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PREFACE

The present volume consists in large part of a series of rather extended abstracts of longer papers which have accumulated during the after-war conditions of printing. Nine are doctors' theses, most of which are very much condensed from the original.* In nearly every case this condensing has been done by the editor, who, therefore, must assume a secondary share of responsibility for the manner of presentation and the selection of features to be presented.

The first three articles deal with the wave-phase localization of sound. Here we are fortunate in having the co-operation of Professor Stewart, Professor of Physics, who has accumulated evidence which tends to support a different theory from that which has been most strongly supported by evidence in the Psychological Laboratory. Neither point of view is yet fully established, but we must be coming near to a solution of the question as to whether wave-phase localization takes place entirely in terms of intensity or through a specific receptor for wave phase.

The next eight articles deal primarily with problems in the psychology of music. Dr. Knock has investigated a method of training the voice by the aid of the eye. Dr. Gaw has done the pioneer work in introducing scientific vocational guidance in music in a conservatory of music. Dr. Stanton has studied principles of inheritance of musical talent in well known American musical families. Dr. Merry has developed a technique for studying artistic effects of pitch modulation in speech and Dr. Schoen has made a similar study of great singers, particularly with reference to the attack, sustained intonation, and the vibrato. The two brief articles by Dr. Agnew are extracts from a monograph which was unfortunately left unfinished by her untimely death through accident. Miss Wickham's paper represents one of the many examples of new measurement of musical capacity which are being developed in the laboratory.

* The articles by Knock, Gaw, Stanton, Merry, Schoen, Agnew, Bunch, Zuehl and Hansen.

The next two articles constitute one unit in that Dr. Bunch is largely responsible for the development of the pitch range audiometer and its use in medical practice, while Dr. Zuehl has established norms and tendencies in acuity of hearing for so-called normal persons. In his second article he describes a simple substitute for a tachometer.

The last four articles are examples of the effort to establish procedure by careful, critical, and experimental review of practice in vogue. Dr. Hansen's study of serial action, and Dr. Ream's study of the tapping test should serve as a starting point for all investigators who propose to use these tests in applied psychology.

In the process of abridging, elaborate notes of acknowledgment have been eliminated whenever possible. With the exception of the third article, all the studies represent work done in or from the laboratory of the University of Iowa, and to each participant the editor and director of the laboratory herewith expresses his sincere appreciation of the comradeship in research which this volume betokens.

THE EDITOR.

WAVE PHASE IN THE OPEN-AIR LOCALIZATION OF SOUND

by

C. E. Seashore

Introduction to following articles on wave phase; open air conduction; statement of observed facts, dated 1918; outline of laboratory problems, dated 1917.

The rôle of wave phase in the localization of sound has been under investigation in our laboratory since 1908. Interest in the subject started with a curiosity about the nature and laws of the illusion we call the phantom sound. It soon became evident that we had here an important experimental approach to the theory of sound localization. And then came the submarine. It is well known that during the great war the best means we had for locating submarines was a listening instrument in which the direction of a source of sound was located by means of the known laws of this illusion.

As chairman of the committee on acoustic problems in the National Research Council during the war period, the writer organized experimental work specifically aimed at the practical operation of this principle in the war service. Mr. H. M. Halverson was employed as research assistant and devoted his time largely to this problem for three years. The technical account of the experiments in which he took the main part is presented in the following article, to which the present article may be regarded as an introduction for the purpose of orientation. Reports of these experiments, with suggested practical application, were furnished confidentially through the National Research Council from time to time during the war.

As a bird's-eye view, or sketch of the nature and significance of this problem in "high lights," a paper read at the Boston meeting of the American Psychological Association, December, 1918, may be helpful. The facts as known up to that date were stated as follows:

"We undertook, as a war problem, a study of the danger of finding more than one apparently correct location of a given phantom sound. I shall here merely enumerate some of the conclusions at which we have arrived.

We have demonstrated that the most effective way to study the behavior of binaural wave phase is to dispense with the tubes or other conductors to the ear, which have previously been used in all experiments, and simply use open air conduction.

If two telephone receivers, connected in parallel from the same source of a tone, are set up within audible distance in the aural axis of the observer, then, in moving gradually from one to the other, the observer will experience the following result: For each half of a wave length there is a median plane localization which we shall call a loop; and midway between each of these is another median plane localization which we shall call a node. The difference between the two lies primarily in the fact that from the loop the phantom sound moves in the direction in which the observer moves away from the position at which he heard the phantom sound in the median plane; whereas, at each node it moves in the opposite direction. There are also many other differences.

Observer Seashore

Phase	Loop	Node	Loop	Node	Loop	Node	Loop	Node	Loop	Node	Loop	Node	Loop
Average Position	43	54	62	72	82	90	101	112	119	127	139	148	157
Mean Variation	1.0	1.5	1.2	2.0	0.8	1.6	0.2	0.8	0.8	1.8	1.0	1.0	0.7

Observer Halverson

Phase	Loop	Node	Loop	Node	Loop	Node	Loop	Node	Loop	Node	Loop	Node	Loop
Average Position	44	52	62	74	81	90	100	110	119	120	139	150	157
Mean Variation	0.0	0.5	1.4	2.0	0.2	1.6	0.5	2.2	0.6	1.0	0.2	0.6	1.3

All figures are in terms of centimeters, and show distance of the head from the left hand source of sound.

The phantom sound thus is experienced as moving in a series of major and minor loops.[1] The records in Table I are for a sound of 930 v. d., the two receivers being placed two meters

[1] For illustration of this see Figs. 1-3 in the next following article, by Halverson.

apart. The wave length is here 37.4 centimeters, at 80° temperature Fahrenheit. The close agreement of the two observers is to be noted.

This open air method is so superior to the previous methods, that we have followed it entirely in working out various problems. Briefly it may be said that one can demonstrate in the open air all the phenomena of wave phase as demonstrated through conductors and, in addition, many others which could not be brought under control by the earlier methods.

If the two tones beat, the observer standing at any point between the two sources will hear the phantom sound moving in an ellipse at a pace determined by the rate of the beat.

Whether the loop shall lie forward, upward, or back, is, in all cases, a matter of tendency in association, and is immaterial; *i.e.,* as in ordinary location of sound, we cannot locate sound radially in the median plane.

If the sound in the two sources gradually rises in pitch, an endless train of loops and nodes will pass the observer. Indeed, one can make very fine pitch discriminations in terms of the movement of the phantom sound in the rise or lowering of pitch.

In many of the earlier experiments, the simple conception of a single median plane localization was due to the fact that a comparatively long wave; *i.e.,* low pitch, was used.

The most significant thing for practical purposes is the finding that in the phantom sound the various overtones separate and each moves in its own orbit at its own peculiar rate. This timbre analysis is, indeed, very beautiful.

If you energize a telephone receiver with three or four superimposed frequencies, whether in harmonic series or not, each frequency will result in a play of its own phantom sound, and the behavior of each partial in its orbit is the same as if it were the only tone.

If we have a single rich source it instantly breaks up into the fundamental and the various overtones in remarkable purity. Thus, for example, if the telephone be put in the 60 cycle A.C. circuit, a rich tone is produced in which the first overtone is dominant and an untrained observer will instantly locate that as the principal tone.

The significance of this is, of course, clear. While, in the submarine listening, many different conditions obtain, all devices should take into account the danger, even the certainty that a given fundamental tone will have four median plane localizations for each wave length, and that each overtone, or accessory tone, has its own orbit and its own median plane localization. The submarine listener should, theoretically, find a number of median plane localizations; not only for a given pure tone, but median localizations for each overtone, in a complex tone.

Fortunately, some of the median localizations coincide, as in any harmonic series, and it is possible to train the observer to distinguish a node from a loop, and an observer keen in tone analysis, who knows the pitch of the tone which he is to locate, may learn to disregard the intrusion of overtones.

The behavior of the phantom sound, and all its segregated harmonics, or other accessories, may be explained and interpreted in terms of the dynamics of the standing wave.

The hearing of the wave phase becomes difficult and finally impossible as one gets very close to one of the sources thereby making the intensity difference so gross that it can not be overcome by the wave phase difference.

In the open air, the wave phase effect can be obtained by the observer being placed in any direction from the two sources; that is, instead of this effect being obtainable only in the lines between the two receivers, it may be obtained anywhere within the area of audibility.

In a closed room the phenomena of reflection complicated the hearing in a most intricate way but, of course, all in accordance with the principles of sound reflection and interference.

The size of the loops and the apparent loudness of the phantom sound vary in a very intricate but predictable way within the audible area.

The relative loudness at loop and node depends upon the ratio of the wave length to the inter-aural distance. For a long time we had difficulty from the fact that we did not realize that with high tones the quarter wave is so short that the crests may fall entirely within the inter-aural distance and may be lost.

In passing by small stages from one source to the other, one may hear the rise and fall of intensity in each of the components of a tone, strictly in accordance with the laws of interference with the standing wave phase.

We have measured empirically the flux in intensity from one receiver to another with the audiometer, and the empirical curve for observable flux in intensity corresponds with the observed movement of the phantom sound, its apparent loudness and distance in the various parts of its orbit.

The intensity in the two sources may vary very considerably without destroying the wave phase effect.

Both theoretically and practically we may plat a topographical map of crests and valleys representing intensity of sound; and the actual behavior of the phantom sound at any place may be predicted by treating each crest as a source of sound."

So far the first public report. The program on which we were at work in the laboratory at that time may aid in throwing Dr. Halverson's account into relief. I find the following memorandum from 1917:

The Rôle of Wave-Phase Intensity in the Localization of Sound

A. *Two sources:*

1. Transition from absolute intensity to relative intensity localization.
2. Result of relative intensity due to stimulation of both ears from each side.
3. The empirical curve for flux in intensity from L. to R.
4. Result for tones composed of three elements of pitch.
5. Result for tones of unknown pitch elements.
6. Pitch limits for localization with pure tones.
7. Effect of absolute intensity with pure tones.
8. Effect of absolute distance to source from the ears.
9. Effect of distance with reference to fraction of wave length.
10. Range of effect of reflection.
11. Characteristics of passage of tone at a minimum.
12. Characteristics of passage of pure tone at a maximum.
13. Relation of open ear localization to localization in T-tubes.
14. Relation of open ear localization to beating tones with tubes.
15. Relation of open ear localization to tones in open air.
16. Limits of pitch differences in the two sources.
17. Relation of theoretical center of head to actual ear distances.

18. The effect of varying radial axis upon the center of the head.
19. Gradual rise in pitch described in terms of rotation of sound.
20. The swinging of one source as a pendulum described in terms of rotation of sound.
21. The effect of pure tone on one side and unanalyzed rich tone on the other.
22. The effect of fundamental on octave; also other intervals.
23. Nodes for different kinds of noises.
24. Wave-phase in Starch's norm for perimetry of sound.
25. Relation to confusion points.
26. Intra-cranial localization.

B. *One source:*

1. Verification of nodes for sound from one source.
2. Crucial differentiation between internal conduction and conduction around head.
3. Use one receiver and sound reflected from the wall for the other.
4. Describe rise of pitch in terms of rotation.
5. Effect of radial direction from center of the head.
6. Check in monaural hearing.

C. *Three or more sources:*

1. Effect of one real and one phantom sound.
2. Effect of radial change and direction of both real and phantom sounds.
3. Elements of fusion.

D. *General application to all normal hearing of direction.*

E. *Genetic theory of space perception in hearing.*

On the theoretical side the fundamental issue arose: does the ear have a localization mechanism for wave-phase as such, or is the wave phase localization reducible to the binaural intensity principle? Frankly we approached the subject with strong convictions in favor of the latter. For a deeper appreciation of the other alternative we are indebted to Professor G. W. Stewart, who has pursued the same subject from the point of view of physics with notable results.

THE ROLE OF INTENSITY IN AUDITORY WAVE PHASE

by

HENRY M. HALVERSON, PH.D.

Fundamental facts observed; the phantom at the loop; the phantom at the node; relative intensity for each unit field, (methods A and B); comparison of tones of different pitch; effect of direction of the current; variation in absolute intensity of the sources; difference in intensity of the two sources; relation of distance to loudness; effect of moving one source; localization outside of the line of the receivers; timbre; phantoms of fundamentals and overtones.

Wave phase localization can be studied best perhaps under normal conditions; *i.e.,* without the aid of conductors for the ears. In our work, at least, it has been found profitable to do away with artificial means as far as possible. The apparatus is indeed simple, consisting merely of a tone generator (a Leeds and Northrup oscillator) and two telephone receivers with the necessary wiring for connections. The receivers face each other at such distances as the experimenter may elect, the intensity and pitch of the tone under control of the experimenter. Observations are taken from a meter stick which is suspended overhead between the receivers.

Fundamental facts observed

The resultant of two tones of the same pitch, produced under conditions as described above, is a phantom sound which behaves in accordance with certain predictable conditions, determined almost wholly by the wave length of the tone.

Let us consider for the moment the stationary wave, which results when two sources emit tones of equal wave length, or approximately equal amplitude, and moving in opposite directions. Case A, Fig. 1 shows two waves moving in opposite directions (the thin wavy line starting at the R side, and the dotted wavy

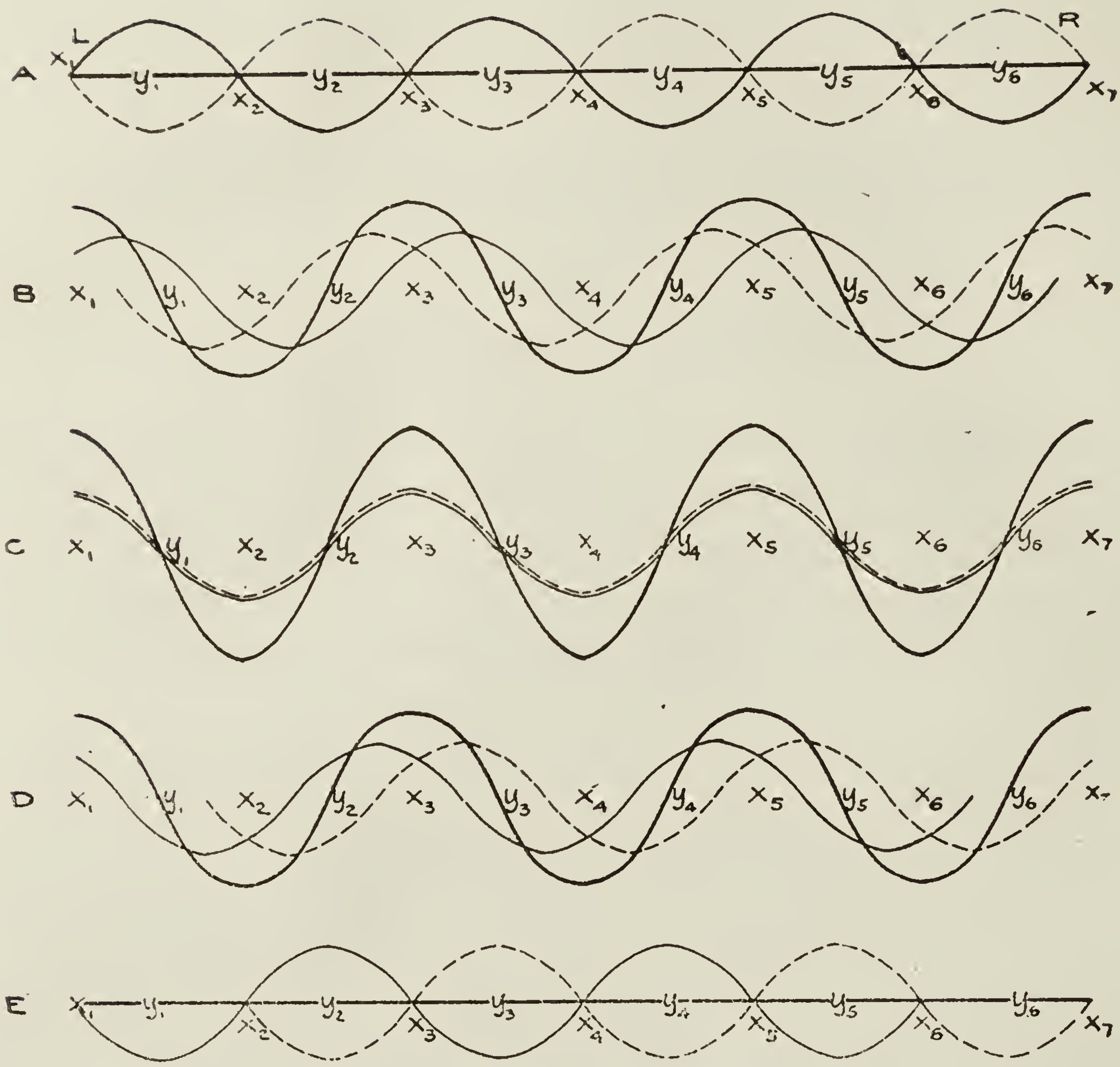

FIG. 1.—The standing wave in relation to wave phase localization; A, wave phase in opposition; B, C, D and E, one wave leading by ⅛, ¼, ⅜, and ½ wave length respectively.

line starting at the L side). As the phases of the two waves are diametrically opposed at every point of the diagram, the resultant is shown by the heavy straight line; *i.e.*, there is no disturbance of the medium. Case B shows the waves as having advanced each one-eighth wave length. (In all these figures the stationary wave is represented by the heavy line). Case C shows the two original waves as having each advanced one-fourth wave length. In this case they coincide throughout their entire course and result in a maximum wave. Case D shows the moving waves in positions another one-eighth wave length further along, and, in Case E each wave has progressed one-half wave length. Thus, for the present purpose, (1) there are several points from L to R where the medium is greatly disturbed; namely, x2, x3, x4, x5, and x6. These disturbance points occur at each one-half wave length. (2) Midway between these positions are points where the medium is but little agitated; namely, y1, y2, y3, y4, y5, and y6.

Let us note the changes in localization which occur at various positions in the axis of the receivers. In some instances the phantom sound moves in the same direction as the head is moved, and in other instances it moves in the opposite direction. Or, more concretely, let the head be held in the position of x4, Fig. 1, the nose being the indicator of position. With the axis of the ears parallel to the axis of the receivers the phantom sound will be observed to be somewhere in the median plane, clear but remote. This position is known as a "loop" center. A slight shift of the head toward either y3 or y4 will quickly displace the position of the phantom sound in a graceful curve in the same direction in which the head is moved. If the head is moved far enough in either direction the phantom sound will come to the level of the receivers and approach the ear from the side toward which the observer is moving. If the head be held in the position of y3, the phantom sound, as such, may be said to have disappeared within the head. However, the sound has now suffered such change in quality by the addition of confusion tones that it is hardly recognizable as the same tone. Localization at this point is thus median but intra-cranial and is known as a "node." Moving the head slightly toward either side causes the phantom sound to appear immediately outside the ear. A still greater movement of the head will bring the phantom in a graceful arc around to the loop center.[1]

The fundamental characteristics which distinguish the loop and the node may be enumerated as follows:

The loop: (1) The phantom moves in the same direction as the head. (2) The phantom is at its maximum distance from

[1] The writer takes advantage of his proof-sheets to add that the intra-cranial localization now appears to be illusory. The phantom moves quickly from one side of the head to the other and is interrupted as moving *through* the head, or else it exists at both sides simultaneously and is compromised under the task of localization as within the head. See his subsequent experiments to be reported in *Am. J. Psychol.*, 1922, 32, April.

the head and its minimum intensity. (3) The phantom moves swiftly, but gracefully, from right to left and *vice versa* with movement of the head. (4) There is no confusion involved with the localization of the phantom and no confusion tones are apparent.

The node: (1) The direction of the movement of the phantom is directly opposite to that of the head. (2) Sound is of maximum intensity immediately as it reaches the means. (3) The tone is richer and fuller than at any other position, possibly due to the addition of overtones and the marked increase in intensity. (4) The phantom moves more swiftly (than in the loop) from left to right or *vice versa; i.e.*, from one ear into the other. (5) Confusion tones are very prominent and tend greatly to hinder localization.

It will be noted that the points of maximum amplitude occur at each one-half wave length, and the points of minimum amplitude are midway between these. More specifically, with the receivers at three wave lengths apart, a maximum point appears exactly in the middle with similar points each half wave length on either side and the minimum points alternate with these. This is seen most clearly in Case C, Fig. 1.

By shutting off one ear from the sound and moving the head to and fro between the receivers (the side of the head parallel to the axis of the receivers) it is comparatively easy to ascertain points of maximum intensity and points of minimum intensity. A tone, 682 d.v., at 90° Fahrenheit has a wave length of 51.5 cm. Hence for every 25.7 cm. we may look for a maximum and, midway between these, a minimum. Averaging the results of twenty-five trials for each of two observers, we have the following:

1. Maxima at 129.2, 102.7, 76.9, 51.7, 25.7 cm.; or a maximum for each 25.8 cm.

2. Minima at 116.4, 90.0, 64.5, 38.6 cm.; or a minimum almost midway between the successive maxima.

In the various cases of Fig. 2 the distance from receiver to receiver is 154.6 cm. Midway between the receivers, 76.6 cm., (0.6 cm. from the middle point) is the maximum point x4 which corresponds with our observations and coincides also with the disturbance point y4 of the standing wave. In the same way it may be shown that all our results correspond quite exactly with the conditions of the standing wave. It seems clear, then, that there are points of interference in the plane extending between the receivers and that between these points are other points of reinforcement.

Having established that points of maximum and minimum intensity persist in regular sequence between the receivers, it remains to determine the empirical curve for flux in intensity over the same course. Case B, Fig. 2, represents the ideal curve for

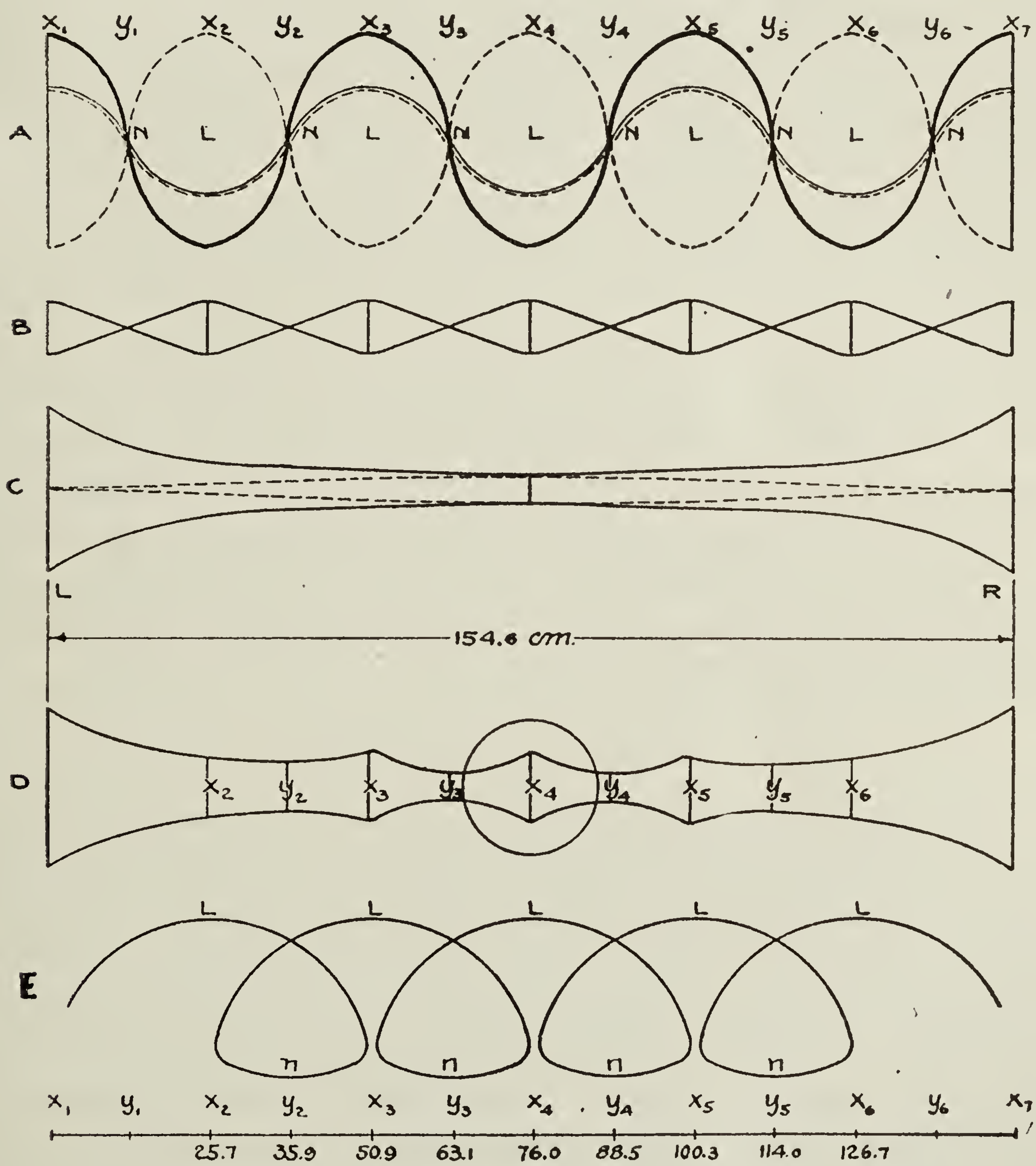

Fig. 2.—A maxima and minima in relation to loops and nodes; B, the effect of interference on intensity; C, the effect of distance on intensity; D, combination of D and C; E, the course of the phantoms through loops and nodes, the relative size of the head indicated by the circle.

relative intensity (relative intensity in this case meaning intensity resulting from the fusion of two tones, one from each receiver) between the receivers. In other words, the ideal curve is one in which the minima are of zero intensity, while the maxima are quite outstanding. The absolute intensity of the sounds from the receivers is ignored in this curve. Case C shows the curve for absolute intensity as determined mathematically. With but one receiver working, its sound is just audible at the other receiver. The vertical lines represent the intensity at one point; the dotted lines represent intensities from the opposite sources, which are quite incapable of much action due to the overwhelming intensity of the near receiver. From our observations we know that neither Case B nor Case C represents the real conditions for flux in intensity. What we do find is the intensity represented by some such curve as Case D, the resultant of the curves for relative and absolute intensity. According to this curve there are at least three very distinct loops; namely, x3, x4, and x5, while there are four good nodes, y2, y3, y4, and y5. Our observations bear this out. Trained observers may with difficulty localize loops x2 and x6 also; the absolute intensity at these points, however, precludes accurate observation. In Case D the relative size of the head is indicated by the circle.

Case E shows schematically the survey of the phantom sound as the observer passes from one side to the other. This will be illustrated in more detail in Fig. 3.

The phantom at the loop

The path of the phantom about the head is illustrated in Fig. 3. The observer first localized a loop center (median) and then moved to the right, progressing by steps of 15 degrees each, calling out the position in each case until the next loop center was reached. He then returned to the left, over the path which he had come, calling out the position as before, until he had attained the position of the first loop center. This procedure was then repeated. The numbers written below the diagram are those of three observers and represent an average of ten trials for each at each position.

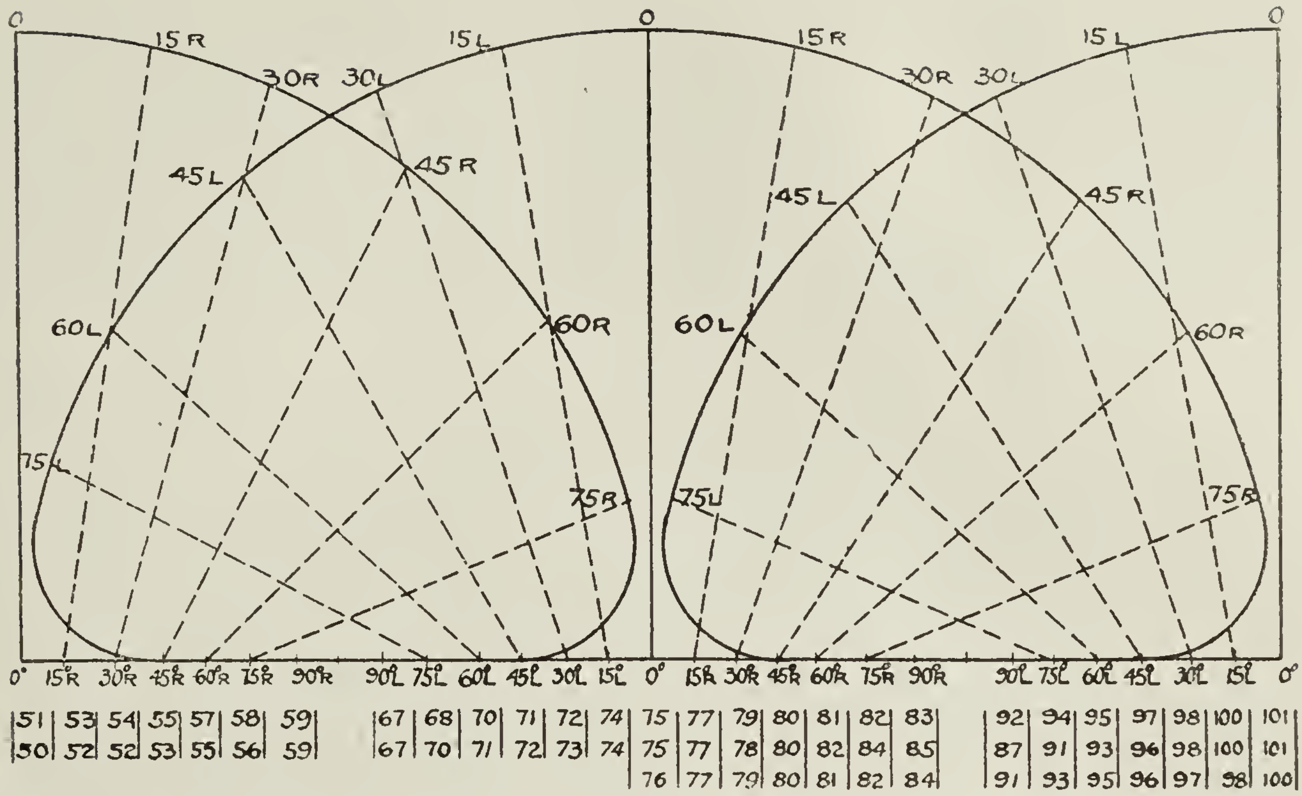

FIG. 3.—The course of the phantom through its cycles in one wave length; the numbers at the bottom give the empirical localization of the phantom at successive 15 degree steps by each of three independent observers.

For instance, if the observer N is at 51 (0° on the base line at the extreme left) he localizes the phantom in the median plane. In this case we represent the phantom position in the direction of the line 0 - 0. Moving the head to the position on the base indicated by 15° R (53 cm.) the phantom has now moved 15° to the right and is in the direction of the line 15 - 15. In this manner it is possible to pass along the base line and tell just how localization holds at any given point. Thus, by the time observer N has moved to 59 the phantom has passed down to the ear level and remains somewhere in the region of that ear (right) until he reaches 67 about the 63 cm. point when it shifts to the left ear. From here it moves around the head until at 75 it has returned to the median plane, a position exactly similar to the one from which he started. The ground covered represents just one-half wave length; the remaining one-half wave length shown in the figure takes the observer through another localization tour similar to the one described.

By applying the principle here involved the movement of the phantom across the entire space separating the receivers may be definitely and accurately predicted and represented, as in Case E,

Fig. 2, when three wave lengths separate the sources. The loops occur at the x's and the nodes at the y's. By passing the eyes up to Case C, Fig. 2, the exact relation between loops and nodes with maxima and minima may be readily determined. Their relation to the standing wave may be ascertained by sighting up to Case A, Fig. 2.

The phantom at the node

When the head first approaches the position of a node the phantom sound has reached a position just opposite the ear toward which the observer is moving (90° from the median plane). At this point no sound is audible at the other ear.

However, if the head is moved farther along, a position is soon reached where the sound is audible in both ears. At this point the observer balances or weighs one sound against the other. There is no fusion of sound at this point nor at any other point within the node. This is the center of the node.

Let the observer now move his head still farther in the direction in which he has been moving and he will come to a position where the sound is inaudible at the first ear but beats with considerable force upon the second ear.

The entire distance covered during the shift just described (the node) is of some extent. Observations on the two most favorable nodes (those nearest the center of the field) reveal the following facts as given by the writer's introspection for one "round trip" of the phantom.

The width of the node averages 7.1 cm (682 d.v. tone). Just when the sound becomes audible in the second ear is difficult of observation. Its growth in intensity at that ear is imperceptible at first due to the strong intensity at the first ear. The quality, intensity, and extensity of the tone at the node differ so greatly from the phantom tone at the loop that for the trained observer there is no mistaking one for the other. The tone at the node is like the blast of a tiny steam whistle immediately outside the ear, or ears, while the phantom tone elsewhere resembles a pure subdued tone of a moving receiver. There is no such thing as a median localization at a node. The thing we do is to maintain an equilibrium of the two sounds as described above. Starting at the loop center, the phantom is high up and far away—60° up front. Upon moving to the right the phantom also moves to the right, but down toward the source at that side. When the phantom has reached 45° right, it has not changed in quality or size or strength. From now on until the time when the phantom reaches the ear level it changes greatly in quality. It seems quite as though a second sound were reinforcing the phantom so that the latter now appears to be growing in size and strength. At 60° it is stronger and larger. At 75°, although it has position, it has no definite outline or size and is beginning to "ring." It has not attained great strength. From 60° or 70° down to 90° (depending upon the absolute intensity) I am not so sure that the phantom is all phantom. I have the feeling that, as the phantom passes the 45° point, another sound of the same pitch combines and possibly interferes with it with increasing insistency until upon its reaching the 90° point the phantom is completely overwhelmed by the second sound. As the head is moved on, this sound predominates until, presently, a third sound, at first faint, is heard at the left ear. This sound increases rapidly in intensity until it equals the second sound and then finally surpasses it. At this instant the sound is stronger in the left ear; but, in its passing from one ear to the other, I am not conscious of change in localization; only a shift in intensity occurs. The sound at the left (90° L) soon becomes the only audible source; and, after a short period, I can detect in this mass or jumble of sound the phantom at, or near, 75° left. It is, however, not the perfect phantom we started with. It resembles the phantom at 75° right. From now on until the phantom attains the 45° point, this sound at the left ear adheres to the phantom, surrounding it, as it were, with a fringe which gradually recedes toward the center or phantom proper until the latter emerges at 45° left. From this point until the phantom reaches the loop center it undergoes no change in size, quality, or other feature.

Relative intensity for each unit field

Within the field of localization each one-half wave length may be looked upon as a unit localization field; for, within certain limits, each successive one-half wave length approximates an exact duplicate of the preceding one-half wave length. A study of one of these units should reveal the general characteristics of each unit field; and, incidentally, that of the entire field of localization. We shall arbitrarily set as the limits of this unit any two adjacent loop centers (x's), the mid-point being the node between them. The present results are obtained wholly from binaural hearing while the intensity observations spoken of before (cases B and C, Fig. 2) were obtained monaurally. The binaural report corroborates and strengthens our monaural intensity observations.

Method A.—The procedure was as follows: The observer was asked to find a point where the intensity was weakest. When this point had been established (ten trials) he was asked to move his head slowly to the right (retracing his steps as often as expedient) stopping at the following points in order: (1) where the first notable increase in intensity occurs; (2) the point where there is no perceptible increase in intensity; (3) the point just preceding that where the intensity begins to wane; (4) the point where there is no apparent further diminution of intensity; and (5) the center of the minimum intensity point.

During the procedure the observer was cautioned to neglect localization and focus the entire attention on intensity. As a matter of fact it is quite impossible to ignore localization altogether, but the experimenter is convinced that localization did not interfere seriously with the judgments. A later experiment confirmed this conviction.

The data obtained from two adjacent unit fields may be briefly stated as follows:

1. There is on each side of the loop center a distance of 4.2 centimeters within which the sound is of minimum intensity.

2. Midway between the loops (at the nodes) is another "stretch" averaging 6.7 cm. in which the intensity is at a maximum and fairly constant although the bulk of it shifts from one ear to the other.

3. Between these positions are short stretches, averaging 4.7 cm., within which the intensity rapidly increases or diminishes, depending, of course, upon the direction of the movement of the observer's head.

These results are based on the figures obtained from three trained observers, H, K, and N. In finding the length of the stretches for both maxima and minima two positions were used in each instance. Four stretches were observed in obtaining the extent of the intensity transition positions.

One of the principal reasons for performing this experiment was to ascertain whether the minima and maxima are distinct "points" or whether they appear more as "stretches." The results indicate that the latter is the case. The fact that transitions in intensity take place quickly with slight movements of the head is upheld in monaural hearing. The increase in intensity usually occurs while the phantom is passing from 45° L or R down to 90°. The diminution in intensity accompanies the opposite movement of the phantom over the same ground. All observers find that there is a tendency to see if they can withdraw just a little farther away from the critical point and still maintain that same intensity.

The figures in Table I represent fairly the two unit fields as observed by three different people. The same data are graphically represented in A and B, Fig. 4.

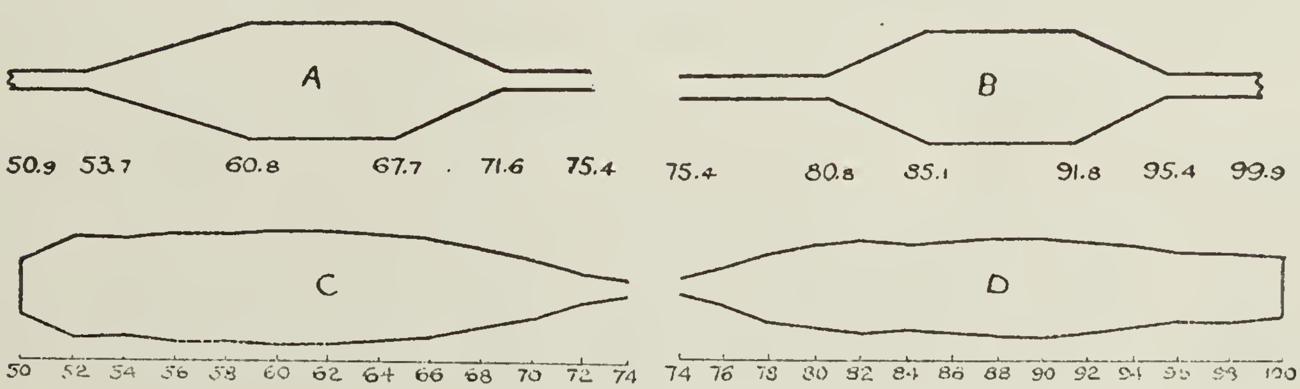

Fig. 4.—Variations in intensity of the phantom; A-B, as observed introspectively; C-D, as measured by the audiometer.

Method B.—This consisted of a series of judgments on paired intensities in which the intensity at prearranged positions was successively compared with the standard intensity at a particular point. A Seashore audiometer was inserted into the telephone

Table I.—Intensity limits as observed

	Minimum Center	Minimum Limit	Width of Maximum	Minimum Limit	Minimum Center
E	51.4	54.1	60.5 — 68.8	71.9	75.2
K	51.0	52.5	62.0 — 66.9	71.0	75.6
H	50.3	54.4	60 — 67.2	71.9	75.4
E	75.2	83.0	84.3 — 92.8	96.5	101.8
K	75.6	77.7	86.15 — 92.0	96.2	99.1
H	75.4	81.7	84.95 — 90.6	93.3	98.8

circuit which permitted the experimenter to control the intensity of the sound at will. The procedure in brief was as follows: The observer took his position at 74 of the centimeter scale, which is one of the weakest intensity points binaurally, and the standard intensity (36 of the audiometer) was sounded twice for a space of two seconds each, with a second's interval between. Then, as quickly as expedient, the observer assumed a second, pre-arranged, position, and the standard intensity was again sounded in the same manner, following which the observer passed judgment as to whether the sound at the second position was stronger, weaker, or equal to the sound heard at 74—the object being to find what intensity at the second position, in the opinion of the observer, is equal to the standard intensity at 74. There were twenty-five positions at which intensities were compared with that of the standard at 74. In experimenting the points were taken at random, no two adjacent positions being taken in succession. These points, with their corresponding audiometer steps, are shown in Table II, and C-D, Fig. 4. The figures for

Table II.—Intensities as measured with the audiometer

Position / Observer	50	52	54	56	58	60	62	64	66	68	70	72
E	33.4	32.2	32.3	31.3	31.2	31.1	30.2	32.4	32.5	32.9	33.7	34.4
K	33.6	30.8	30.7	29.8	29.8	29.4	29.7	30.5	31.7	32.1	33.2	35.5
H	31.3	30.6	31.8	29.7	30.2	30.1	30.5	30.5	30.5	32.5	34.1	34.9
Average	32.8	31.2	31.6	30.3	30.4	30.2	30.1	31.1	31.6	32.5	33.7	34.9

Position / Observer	76	78	80	82	84	86	88	90	92	94	96	98	100
E	34.4	32.7	31.5	31.6	33.2	32.9	32.3	33.8	32.8	33.2	33.6	33.4	35.1
K	32.6	31.7	30.4	29.5	28.8	29.8	29.8	29.9	30.7	30.6	31.7	31.3	31.4
H	34.5	32.8	31.6	31.5	30.4	30.0	29.0	29.0	29.8	30.5	31.4	31.8	31.5
Average	33.8	32.4	31.2	30.9	31.2	31.0	30.7	30.7	31.1	31.4	32.2	32.2	32.7

each observer represent an average of ten judgments at each position. These may be compared with the averages of the three observers at each position. The intensity at position 74 is not indicated in the table as it was used as standard.

Attention is called to the matter of interpretation of the figures. The standard intensity (36) was the strongest intensity used. At no other position, according to the data, is it necessary to use as high a step as 36 to equal in intensity the standard at position 74. Hence, the lower the figures at any position the less the intensity required at that position to equal the standard intensity at 74. In a wider sense this means that, under the conditions of open air wave phase localization, those positions which are here represented by the lower figures are stronger in intensity than positions represented by higher figures.

Results.—(1) For each wave length there are two points where the intensity is comparatively weak, and two other points where it is strong. (2) The weak intensity points coincide with the loop centers, the strong with the nodes. (3) Empirically, there is a fairly speedy transition from the strong to the weak intensity points, which, to the observer, appears to take place even more quickly. (Note Fig. 4.) (4) The strong intensity points represent longer stretches than the weak points. (5) The data show a close agreement between the results as obtained by direct observation and by the audiometer. (6) It is probable that (a) minima appear to be greater stretches to the observer than they are in fact; (b) maxima are greater stretches than they appear to the observer, although not so regular; and (c) transition stretches in intensity from weak to strong, and *vice versa,* are not as short as they appear to the observer.

Table III.—Variation in nodes and loops with pitch

Frequency	Loop	Node	Loop	Node	Loop	Node	Loop
930 d.v.	62.0	73.0	81.5	90.0	100.5	111.0	119.0
682 d.v.	50.9	63.1	76.0	88.5	100.3	114.0	126.7
402 d.v.	43.8	63.3[1]	85.1	109.3	126.5	147.8	169.4

[1] Observer experienced both loop and node in this instance.

The average distances from loop to node for the frequencies used are: for 930 d.v., 9.5 cm.; for 682 d.v., 12.6; and for 402 d.v., 20.9 cm.

In gradual raising or lowering of the pitch no change in the median localization of phantom takes place if the head is held steadily at the mid-point between the receivers; but, when the observer's head is placed to one side of the mid-point of the receivers, a series of loops and nodes will pass the observer's head moving toward the mid-point if the pitch of the tone is gradually raised, and the same series will pass the head moving in the opposite direction if the pitch is lowered.

The movement of the phantom, loops, etc., may be observed by two methods. The observer may localize one of the loop centers when the tone is of a comparatively low pitch, and then, as the pitch is raised, move toward the mid-point of the field in order to maintain that median localization of the moving phantom. When the pitch is lowered he will proceed in the opposite direction. Or, the observer may localize a given loop center, as above, and then, as the pitch is changed, maintain this position throughout, the object being to note the number and direction of the movements of the phantoms which come within his range. The observer in this instance should keep in mind that the phantom always moves in a direction opposite to the movement of the loops and nodes.

If the tone from one receiver is made to differ in pitch from the tone of the other receiver by one double vibration per second, a series of loops and nodes will pass the observer at the rate of a loop and a node per second. If the difference in pitch is increased the rate at which the loops and nodes pass will be correspondingly increased. If the pitch is lowered, the rate will be slower. This experiment may be observed by holding tuning forks of slightly different pitch one to each ear.

Effect of direction of the current

It often becomes necessary to disconnect the parts of the apparatus to meet the various conditions of experimentation. So it came about that one day, much to the surprise of the experimenter, it was discovered that the observer was localizing loops in the approximate position in which nodes usually obtained, and that the nodes had taken possession of the loop points. In other words, the positions of the loops and nodes were exactly reversed.

The receivers, up to this time, had always been connected in series with the generator. The terminals of each wire had been labelled so that in re-connecting everything might be in place. Upon tracing out the connections, therefore, it was found that the position of the terminals of two wires had been reversed. As previously arranged, the alternations in the current producing the tone so affected the receivers as to cause simultaneous magnetizations of the receivers at one instant, followed by simultaneous demagnetizations the next: the diaphragms of the two receivers were at one instant moving simultaneously toward the magnets and at the next instant in the opposite direction. The result of the propagation of sound waves from the receivers under these conditions is a standing wave as represented in Fig. 1. On the other hand, the reversal of the current in one receiver results in a magnetization in one receiver simultaneously with a demagnetization in the other receiver: therefore a crest of the sound wave emanates from one source at the very instant that a valley issues from the other, and corresponding points in the standing waves are exactly one-fourth of a wave length removed; *i.e.,* maxima exist where minima formerly existed and vice versa.

In order that future experimentation might not be handicapped by recurrences of this nature, observations were made on the positions of maxima and minima of intensity in all the possible conditions under which they exist. These may be listed as follows: (1) receivers in series, magnetizations in both receivers occurring simultaneously; (2) receivers in parallel, magnetization in both receivers occurring simultaneously; (3) receivers in series, simultaneous magnetization of one receiver with demagnetization of the other; (4) receivers in parallel, simultaneous magnetization of one receiver with demagnetization of the other.

These experiments warrant the following conclusions: In cases (1) and (2) above, maxima obtain at the positions where in cases (3) and (4) minima obtain: and, conversely, in cases (1) and (2) minima obtain at the positions of maxima in cases (3) and (4). In cases (1) and (2) the series of maxima and minima appear in order in the line of the sounds, with a maximum always at midfield; while in cases (3) and (4) we find a like series with the exception that a minimum holds the midfield position.

As regards intensity, in binaural hearing, the loops experienced in cases (1) and (2) at positions 102, 76, 51, and others, are replaced in cases (3) and (4) by nodes; while, in like manner the nodes of (1) and (2) at 116, 90, and 65 are replaced by loops in cases (3) and (4). These are, of course, matters of common sense and should have been taken into account in the original use of revisions for this present purpose.

Variation in absolute intensity of the sources

Experiments were made with three different intensities distinguished roughly as strong, medium, weak.

In order to obtain the tone of strong intensity a current of 2.4 volts was introduced into the circuit of the electro-magnet of the generator, and for the medium intensity 0.8 volts. The tone of weak intensity was obtained by running the generator without any re-enforcement of its electro-magnet. In all cases the distance between the sources was three wave lengths, pitch 682 d.v. The results of the observations may be summarized in the statement that these marked differences in intensity had but slight effect upon precision in locating the loops: but there was a marked tendency to confuse at the nodes, for these extreme intensities. The nodes "widen out" upon conditions of great intensity and "narrow down" when using sounds of weak intensity.

For most observers the intensity produced by the introduction of one Edison cell (0.8 volts) in circuit with the electro-magnet of the generator is conducive to the best results in localization. It is with this "set up" that most of the observations have been obtained.

Difference in intensity of the two sources

By introducing the necessary resistance into the circuit of one of the receivers, the absolute intensity may be so reduced that the observer can barely distinguish the sound at midway. Few observations have been made under these conditions, but good observers may still distinguish the loops and nodes with precision.

The experiment was tried of reducing the intensity of one of the sources while the other was kept constant. With the sources three wave lengths apart no changes in localization were noticeable. There was, however, a limit to which the intensity of the one could be reduced without losing its valence on localization. Hence this mode of procedure was discontinued.

In another procedure, the intensity of the sources was reduced to a point feasible to work with at close range and the observer was requested to press the receivers securely against the ears and localize the phantom. He was then asked to note carefully what change, if any, took place in the position of the phantom when the intensity of the source (the left receiver) was reduced, the other remaining constant.

The effects of varying the intensity of one source are as follows: (1) With the phantom localized in the median plane to start with, reducing the intensity of the left receiver causes the phantom to move slowly but with a sweeping motion in the direction of the right ear; when the reduction of the sound at the left ear has reached a certain stage the phantom has disappeared and only the sound at the right is audible. If now, the intensity of the left source be increased until it equals that of the right source, the phantom slowly moves from the right ear back to its original position in the median plane. (2) The observer is not at all aware of the diminishing intensity at the one receiver. The effect of this reduction in intensity is such as to draw the observer's attention to the seemingly increasing intensity at the right ear. (3) The movement of the phantom from the median plane toward the right ear is accompanied by a change in the quality of the tone: from an approximately pure tone the sound becomes gradually more and more complex until the entire sound is encamped at the right ear. (4) The phantom loses its clearness rapidly when the intensity at the one ear is reduced.[1]

The experiment was repeated with the sources one-half wave length apart (25 cm.); *i.e.,* the sources were about five centimeters distant from the ears. The results were identical with those stated above.

[1] The writer's subsequent experiments (see footnote page 9) indicate that this movement under the variation of intensity may be discontinuous.

Relation of distance to loudness

A study of the effect of distance upon intensity was made under two conditions: (1) when the sources were very close together,—two wave lengths (approximately 100 cm.) apart; and (2) when the sources were far apart,—five wave lengths (250 cm.) apart. The sound was comparatively loud, there being 1.6 volts in circuit with the magnet, when as in the standard procedure we used only .8 volts. This study led to the following conclusions:

A. *Sources two wave lengths apart.*—The absolute intensity of the sound is a strong factor binaurally. Localization of the phantom at the loop is easily observable but only within sixty degrees each side of the median plane. The intensity of the phantom sound at the loops is an outstanding feature. The phantom is very clear in spite of its great intensity. It is the opinion of the observers that it is both "brighter" and larger than for weaker intensity. Monaurally the maxima and minima of intensity are difficult of location. The absolute intensity "fills in" the minimal points so that they are scarcely distinguishable from maxima. Careful observation, however, will disclose at least two minima.

B. *Sources five wave lengths apart.*—Absolute intensity is not so important a factor binaurally with this distance. Relative intensity as represented by maxima and minima is very prominent. The phantom is easily observable, more so in some loops than in the nodes. The phantom is of weak intensity. While it is clear and distinct, it is not as "bright" as at three wave lengths distance, yet, practically, it is as easily localized because of its definition. Monaurally, the maxima and minima are more easily localized than at three wave lengths, but there are certain maxima and minima which do not stand out as clearly as others.

Effect of moving one source

First Method.—The observer found a loop center and maintained this position throughout the experiment. When the right receiver (R) was moved outward away from the observer the phantom was observed to move from its median position toward the left of the observer until it reached the position at 90° L. Soon a sound was heard at 90° R. and then the phantom slowly mounted from this position, moving up the right side of the head, until it reached the median position. As the phantom reached the positions 45° L, 90° L, 90° R, 45° R, and median, the observer called them out and the experimenter recorded the position of R (receiver) in each case. Ten trials were taken at each position. After the receiver had reached its outmost position the experimenter reversed the procedure by moving the receiver back slowly to its original position at 151.6, the observer calling out the positions as before, only in reverse order.

Second method.—The observer moved his head simultaneously with that of the receiver, with the end in view of keeping the phantom always in the median plane (loop center). As the receiver was moved away from the observer to the right, it was noticed that he moved slowly in the same direction. When the receiver was moved in toward the observer, he retreated before it. Records of the positions of the observer's head were taken only at positions where he formerly recorded 45° L, 90° L, 90° R, and 0°.

Third method.—Both receivers were simultaneously moved a distance of one wave length and at the same rate away from and then toward, the observer.

Fourth method.—With the observer's head fixed, both receivers were now moved simultaneously in the same direction, the distance between them remaining the same throughout. As the receivers were moved in one direction, the observer reported that the phantom moved in the opposite direction.

The results may be summed up as follows: (1) The phantom makes one complete revolution about the head with each whole wave length change in the position of one receiver. (2) The phantom behaves in exactly the same manner as when the head is moved. (3) There is no change in the character of the loops and nodes, nor in the movement of the phantom under any of these conditions. (4) The phantom moves in a direction opposite to the receiver. The records show that as the receiver is moved to the right the phantom moves to the left, and *vice versa.*

(5) All loop centers move in the same direction as that of the receiver but at only half its speed. (6) The results obtained by moving the receiver through a distance of one wave length are precisely the same as obtain upon moving the head (both receivers fixed) one-half wave length distance. (7) Distance apart of the receivers does not affect phase, provided both receivers are moved simultaneously and at the same rate toward, or away from, the center of the localization field. In other words, when the receivers are moved away from the center of the field no change in localization occurs, but new loops and nodes are added at both ends of the field as rapidly as the distance will permit. When the receivers are moved in toward the center no change in localization occurs but loops and nodes are clipped off at both ends of the field as the receivers near the center. The only observable change is that in absolute intensity and distinctness of the phantom. (8) Moving both receivers simultaneously in the same direction for a given distance, the observer's head remaining constant, produces the same changes in localization, intensity, clearness, and confusion as does moving the head for an equal distance in the opposite direction, the receivers remaining constant.

Localization outside of the line of the receivers

Changes of phase may be observed not only in the line of the receivers but anywhere within audible distance of the sources, as long as the conditions of the standing wave obtain, especially in the space included by the planes of the receivers. In fact, as soon as one comes within clear, audible range of the sound he is impressed with the phantom. By a slight adjustment of the head, the intensity may be shifted from one ear to the other and in most cases the shifting of the phantom sound may be observed, although the exact direction of its movement may not always be perceived. Yet the closer one approaches the line of the receivers the more definite and clear is the movement of the phantom.

Extended evidence on the movement of the phantom at various positions outside of the line of the receivers is lacking. An attempt to secure observations at points four and one-half feet below the sources did not meet with much success, although the figures and introspections are significant. The reflection from the floor, about five feet below became too prominent. Observer N localized medians at 80.5 and 72.3 but reported that they appeared to resemble both the node and the loop. The movement of the phantom at these points was exceedingly rapid. Observer H also met with difficulty. He reported many confusion points, but finally localized three medians, 143.8, 133.4, and 119.9. These medians, H reported, resembled the loop centers, except that the phantom moved in a direction opposite to that of the head. Some of them are like nodes, then, as far as the movement of the phantom is concerned, but in all other respects they favor the loops.

Timbre

Timbre plays a very important rôle in wave phase localization. Wave phase localization is more difficult with noises and rich tones than with pure tones, with the possible exception of the main median localization. A possible explanation for this is that the purer the tone the more prominent and clear become the maxima and minima.

If the sound to be localized is a noise the conditions necessary for the standing wave are negative and no maxima and minima obtain; hence, the intensity of the sound at any particular position in the localization field simply varies inversely as the square of the distance from the sources. Only one median localization is possible with a noise. Other investigation which has been carried on at length in this laboratory substantiates this view. If the sound approximates a noise, such as the hum of an electric motor, in which one or more tones dominate, a median localization for the mass noise can be observed as well as median localization for the dominant tones. These localizations may or may not coincide. Besides the principal median localization positions, there are other positions which have been named confusion points; these turn out to be medians of the dominant over tones.

In localization with a rich tone maxima and minima of the fundamental tone are set up, but the overtones and other attendant tones largely destroy the effectiveness of these by their own standing waves. The pure tone offers the best conditions for wave phase localization.

Phantoms of fundamentals and overtones

Perhaps one of the most significant and most interesting features connected with wave phase is simultaneous double or triple localization of a single tone. A concrete illustration of the above came to the attention of two of the observers while experimenting with a 402 d.v. tone. Besides the regulation loops which always attend the localization of this tone, an extra loop was observed at the position of one of the nodes. This loop had all the characteristics of the ordinary loop with the exception of clearness.

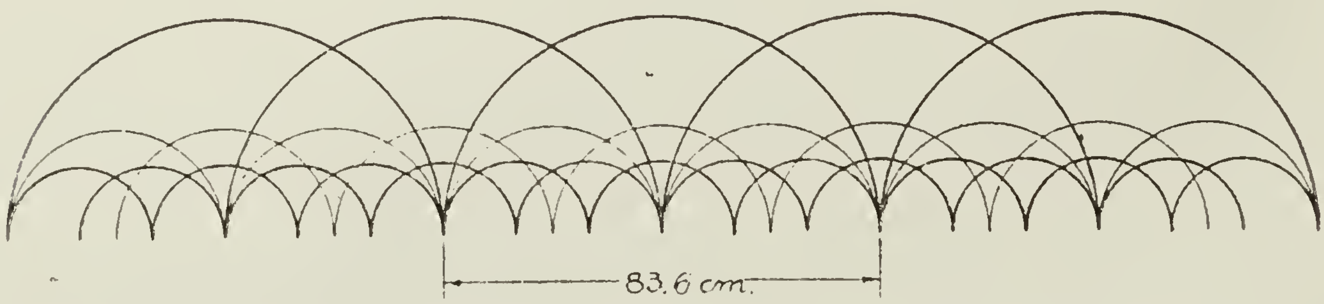

FIG. 5.—A schematic representation of the inter-relations of the phantom of the fundamental and each individual overtone.

Fig. 5 is an attempt to picture the manner of the movements of the phantoms of the fundamental, the first and the second overtones of a rich tone. Schematically the diagram shows that, under perfect conditions, for each wave length (83.5 cm.) of the fundamental tone there should be two major loops of the fundamental tone, four loops of the first overtone, and six loops of the second overtone.

Loop centers of the fundamental and overtones coincide at each of the loop centers of the former. At no other positions do all the overtone phantoms coincide. The size of the loops varies directly as the wave lengths of the tones. The rate of movement of the phantoms varies inversely as the wave lengths of the tones.[1]

[1] In his presentation of his subsequent experiments (see Ed. Note below) the writer has been able further to substantiate these conclusions by showing quantitatively the simultaneous course of the phantoms of the first and second partials of an impure tone.

The present article here comes to a sudden end without attempt to generalize on the data presented. The reason for this lies in the fact that the author transferred to another university where he is pursuing the same problem from the point where he left off. The author's manuscript at the date when submitted, July 1920, contained chapters on that subject, but it has been deemed advisable to withhold publication of them until certain issues which he is now studying have been verified. We shall look forward with anticipation to some contribution toward the solution of the perplexing theoretical questions which are involved in this investigation. THE EDITOR.

As this monograph goes to press it is understood that the principal results of these subsequent experiments will appear under the title, "Binaural Localization of Tones as Dependent upon Differences of Phase and Intensity," *Am. Jour. Psychol.*, vol. 32, April 1922. H. M. H.

THE INTENSITY LOGARITHMIC LAW AND THE DIFFERENCE OF PHASE EFFECT IN BINAURAL AUDITION

By

G. W. Stewart

Part I: The intensity logarithmic law: historical; recent measurements, values of K and lapses in intensity effect; discussion; summary.

Part II: The difference of phase effect: apparatus; quantitative measurements of phase effect; frequency limit of the phase effect; discussion; summary.

Part I: The Intensity Logarithmic Law

Historical. There have been many experiments concerning the effects of intensity difference at the ears upon localization, but until recently quantitative measurements have not been employed. Hovda and the author[1] were the first to ascertain the relationship between the ratio of intensities at the ears and the angular displacement of localization from the median plane. They discovered that if the relative intensities at the ears of a pure tone, 256 d. v., were varied, but with the phase difference maintained at zero, there resulted a displacement of the apparent source of the fused sound from the median plane, toward the side of greater intensity, this displacement, θ, let us say, to the right, and the intensities at the ears, I_R and I_L right and left respectively, having the following relations:

$$\theta = K \log_e \frac{I_R}{I_L}$$

wherein K was a constant for an individual. This apparent source of fused sound seemed to have a position external to the head in a plane approximately horizontal, usually in front rather than in the rear, and the displacement occurred in a circle of fairly constant radius.

Since this publication more extended observations have been

[1] Stewart and Hovda, Psych. Rev. XXV, No. 3, May 1918, p. 242.

made with results that are interesting and of psychological importance.

Recent Measurements: A. *Values of K*

Apparatus. The apparatus used in ascertaining values of K was similar in all essentials to that of Stewart and Hovda.[2] The source of sound was a tuning fork actuated by an electro-magnet which was controlled by a second fork. The observer used stethoscope binaurals and sat at the center of a circular scale in order to ascertain the angular displacement of the image. The intensities were varied by altering the position of one of the receiving tubes at the fork without producing a phase difference, and the relative intensities at the ears I_R and I_L were ascertained by means of a Rayleigh disc.

Procedure and Results. In accord with the logarithmic law, a curve drawn with the logarithm of the ratio of intensities at the ears as abscissae and with angular displacement of the apparent source of the fused sound from the median plane as ordinates, would be a straight line with slope K. The procedure was to take at one sitting a number of observations of θ, the angular displacement, with known relative values of I_R and I_L, the intensities at the ears, and then subsequently to draw the straight line representing the mean of the observations and calculate the value of K from the slope. From 24 to 50 observations were made for each curve, these being scattered so as to be "at random." In Table I. are shown the results thus far obtained, which, though not many, doubtless are sufficient to enable definite conclusions to be drawn.

Table I

Frequency	Observer	Number of Curves	Value of *K*
256	S	3	16°
	B	5	30°
512	B	4	21°
	F	4	14°
	M	4	21°
1,024	B	8	10°
	F	8	7.8°
	M	8	18°

[2] *Loc. Cit.*

The observations of S are taken from the cited work of Stewart and Hovda, the 256 d.v. observations of B were obtained by Mr. E. M. Berry in experiments, as yet unpublished, conducted by himself and Mr. C. C. Bunch; the observations of B for 512 and 1,024 d.v. were made by Mr. Berry in experiments conducted by Caroline McGuire Schoewe, and the observations of F and M were also made with the Schoewe apparatus. In every case the linear logarithmic law seemed to hold, Berry and Bunch showing that it held up to θ but slightly less than 90°. Two conclusions are to be derived from the table, *viz.*, that the constant K varies with individuals and that for an individual it decreases with increasing frequency.

B. *Lapses in the Intensity Effect.*

General Remarks. By "intensity effect" is meant the existence of a θ (retaining above definition) other than 0° when the ratio of intensities is varied. This "intensity effect" followed a logarithmic law in all the cases cited above. Presumably this law is true at all frequencies at which there is an intensity effect, but, without direct experimental evidence, its existence must be an assumption. In the experiments which are now to be cited, though no quantitative measurements were taken, yet no noticeable change occurred in the nature of the intensity effect. Hence the assumption is made that the logarithmic law holds. Experiments to test out this probability should be made and it is the hope of the author that some psychological laboratory will undertake this task. A similar hope should be expressed concerning an extension of the observations now to be described.

Apparatus and Procedure. The apparatus used had been designed to determine quantitatively the effect of phase difference at the ears as affecting localization and is described in detail in a recent article.[3] It consisted essentially of a toothed wheel rotating in front of two bipolar receivers. The currents thus produced actuated two head receivers and these, in turn, were attached in a suitable manner to stethoscope binaurals. With the apparatus adjusted for equal phase and intensity at the two ears, one of the

[3] Stewart, Phys. Rev. N. S., Vol. XV, No. 5, 1920, p. 432.

rubber stethoscope tubes, right or left, was pinched, thus lessening the intensity on that side. Attention was confined to answers to the following questions, using the range of frequencies possible with the apparatus. Is there a rotation of the phantom source in the circular path around the head? Is there single fusion, *i.e.*, but one phantom source? If not single fusion, where are the other phantom sources? These or equivalent questions were asked by the operator who pinched a tube on one side or the other and required the observer to describe to him the motion of the phantom. The operator conducted the experiment in a manner that assured him of the correctness of his observers' replies, keeping the operation at all times unknown to the observer. Frequencies from 200 to 2,000 d.v., with steps of 100 d.v. were used. The tone obtained was not pure, but previous experience with the intensity effect and the nature of the present results conspire to give assurance that no error in the conclusions reached was introduced by the slight complexity in the tone used. Furthermore an effort to make the tone as pure as possible by the appropriate use of inductance and capacity, did not in any way alter the results already obtained.

Results. The results of 16 observers are most easily exhibited graphically in Figs. 1 and 2. In explanation of these figures, the

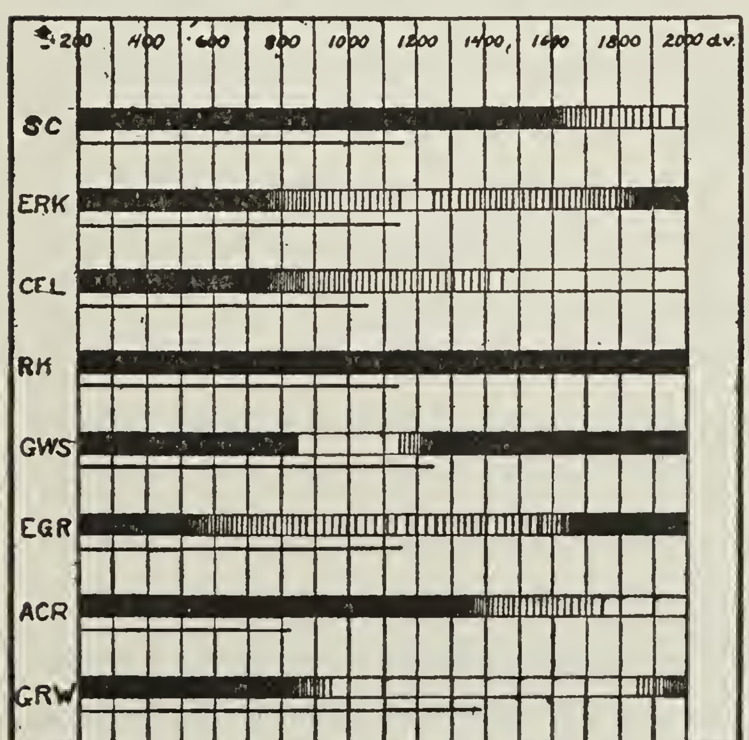

Fig. 1

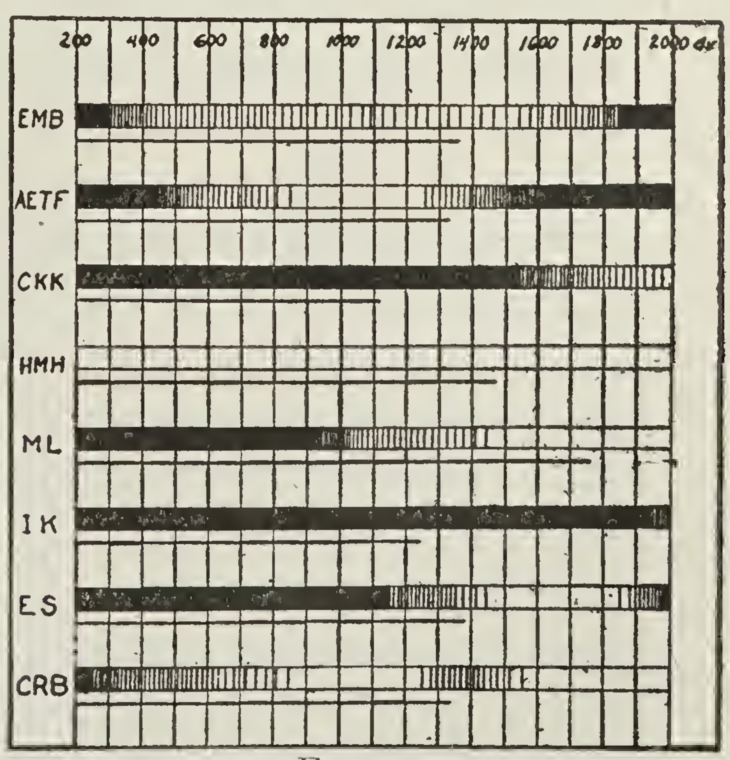

Fig. 2

results of E. R. K. in Fig. 1 will be discussed. First there appears a solid block, then a shaded region, and from 1150 to 1250 d.v. an open block, where there is no connection between the lines running across the figure. Connection, whether by a continuum or by the shading lines, indicates rotation about the head of the phantom produced by alterations in intensity-ratio at the ears, or, in other words, the existence of the intensity effect. In the fully blocked connection, there is "single fusion" and thus one phantom which rotates about the head. The portion connected by the shading lines indicates "double fusion," or the existence of one rotating phantom while another phantom remained in the median plane. Thus with E.R.K. there was one phantom, rotating about the head with variations in intensity ratio for frequencies between 200 and 750 d.v.; likewise between 1850 and the limit, 2000 d.v. There were two phantoms from 750 to 1150 d.v. and from 1250 to 1850 d.v., one rotating and one stationary in the median plane; there was no rotating phantom from 1150 to 1250 d.v., the only phantom being stationary in the median plane. As previously stated, frequency differences of 100 vibrations were used. Thus at 1100 there was double fusion and at 1200 no fusion at all but intermediate frequencies were not tested. The frequency 1150 d.v. shown in the figure was selected arbitrarily as a convenient one to represent the unknown frequency between 1100 and 1200; thus in both Figs. 1 and 2 it is to be understood that the midway records were selected as approximations.

Four of the observers were tested at higher frequencies. Their additional records were as follows: C E L, no fusion from 2000 up to 2950; serious deafness in one ear from 2150 to 2950; no fusion from 2950 to 3950; M L, double fusion between 2100 and 2350, no fusion between 2350 and 2940, double fusion from 2950 to 3850; E M B, double fusion from 2100 to 2950, single fusion from 2950 to 3250, and double fusion from 3250 to 3850; A E T F, single fusion continuous between 2000 to 2550, double fusion between 2550 and 3950; C R B, no fusion continued from 2000 to 4000. These additional data do not introduce any new features, but merely confirm the apparent irregularity of the occurrence of the three conditions of fusion specified.

The results as shown by Figs. 1 and 2 may be stated as follows:

1. The "intensity effect," *i.e.,* the rotation of the apparent source of fused tone about the head, does not exist for all frequencies from 200 to 4,000 d.v. for all individuals.

2. With sixteen observers, ten had a definite cessation of the intensity effect in a certain region or certain regions within the frequency range of 200 to 2,000 d.v.

3. These frequency bands vary in "breadth" or range of frequency and in the frequency of the center of the band, but with one exception all occur above 800 d.v.

4. There exist frequency bands of single fusion, giving but one phantom, this one having a displacement from the median plane depending upon the ratio of intensities at the ears; there are also frequency bands wherein two phantoms are formed, one stationary in the median plane and the other rotating as in the case of single fusion just cited.

5. The records of the sixteen observers do not indicate any "norm" of which the others may be said to be variations.

Discussion

The author is not a psychologist and cannot therefore discuss the significance or general bearing of these results. But it is his hope that one or more psychologists may be attracted by this interesting field of research, which seems barely touched upon by these experiments.

These additional data upon the logarithmic law are of importance in considering the function of intensity in binaural localization, for recent contributions[4] indicate that up to a frequency of approximately 1,200 d.v., intensity is a much less important factor than phase. Not only is there ample quantitative evidence to verify this conclusion, but there is also indirect evidence in the wide individual variation of K as shown in this paper when comparison is made with small individual variations in results with phase differences only.

A criticism may arise because no statement has been made as

[4] Stewart, Phys. Rev. XV, No. 5, 1920, pp. 425-432.

to the relative acuity of hearing of any of the sixteen observers; especially for those frequencies where lapses of the "intensity effect" were found. To be sure, it would have been a good plan to have made such tests. It is improbable, however, that any important changes in our results would be thereby indicated; for in those regions where the intensity effect ceases, the image still remains in the median plane, which would not be the case if there had been any serious deafness of either ear to these frequencies. Referring to the nature of the observations for the value of *K* as recorded above, it can readily be seen that a slight deafness in one ear would cause a shift in the curve along the axis representing the logarithm of the intensity ratio, but would not change the value of K.

There is one apparent inconsistency between the above results on intensity lapses and those gained from common experience. It has been stated that in the absence of an "intensity effect" the phantom remains in the median plane; but this cannot be and is not true when the intensity ratios are very great. For example, with the author, who has an intensity effect lapse in the region of 1,024 d.v., accurate quantitative measurements varying intensities at this frequency with varying interesting ratios, showed that the phantom remained in front until the intensity ratio became approximately 200 : 1, when, intensity ratio being continuously increased, another phantom appeared directly at the side, then gradually increased in intensity while the intensity of the median plane phantom decreased until it finally disappeared altogether. It is to be understood, then, that in the "lapse" region a single phantom remains stationary in the median plane even for values of the intensity ratio which will cause a large displacement for neighboring frequencies, and that no alterations in the intensity ratio, no matter how great, will cause this phantom to rotate, though another distinct image may appear at the side when the ratio is sufficiently great.

The fact that there is a lapse in the intensity effect shows that there must also be a lapse in the logarithmic law, assuming that the latter can be shown to hold at frequencies less and greater than the frequencies within the lapse region.

The author does not assume that these few observations concerning the lapse of an intensity effect are adequately refined or that the series is sufficiently extensive. Inasmuch as he is chiefly concerned with the physical aspects of audition and does not contemplate a continuation of these researches, it seemed nevertheless desirable that the results should be presented, for whatever psychological value they may have.

Summary of Part I

1. The binaural intensity logarithmic law of Stewart and Hovda is found to apply at 256, 512 and 1,024 d.v.

2. The constant K, occurring in the mathematical expression of the logarithmic law, is shown to vary widely with different individuals and, with a single individual to decrease with increasing frequency.

3. A test was made with 16 observers with frequencies varying from 200 to 2,000 d.v., and with four of these from 2000 to 4000, the purpose being to ascertain if an effect similar to the one expressed in the logarithmic law existed throughout the entire range of pitch. The results show that there is such an effect within the frequency range stated, but that with 10 of the 16 observers there occurred one or more groups of frequencies wherein the effect was absent. In addition, with each of 14 of the observers there were one or more frequency regions or bands in which there seemed to be two apparent sources of sound.

Part II: The Difference of Phase Effect

Recently[5] the author has presented quantitative measurements of the binaural difference of phase effect and this brief report is an extension of those results presented in a journal reaching psychologists. By "binaural difference of phase effect" is meant the alteration of the angular displacement from the median plane of the apparent source of the fused sound when varying phase of differences of a given frequency are presented at the ears, and the intensities are kept constant and equal. This "effect" has been

[5] Stewart, Phys. Rev. xv, No. 5, 1920, p. 432.

known for a number of years; a review of the literature is given by the author in the *Physical Review*, IX, 1917, p. 502.

Apparatus. As already described in the former report,[6] the phase differences at the ears were produced by a "phaser" and the observations checked by tuning fork sources. The sounds were led to the ear by rubber tubing and stethoscope binaurals. Open tubes at the ears were also tried and there seemed to be no difference in the effect.

Results: Quantitative measurements of phase effect. The experiments showed clearly that the angular displacement of the apparent source of the fused sound or "image" is strictly proportional to the phase difference at the ears, with, of course, the limiting provision that the linear relation is true only for a difference of phase, θ, less than 180°. At $\theta = 180°$, the image crosses from the maximum angular displacement on one side of the median plane to that on the other side. The experimental procedure was to ascertain this linear relation between θ, the angular displacement, and ϕ, the difference of phase, for a single frequency. Two observational methods were employed. With frequency constant, settings of the phaser were made at "random" by an operator and the observer recorded the corresponding values of θ. When the observations were plotted with ϕ and θ as coördinates, a straight line representing the mean of the observations was drawn and the slope, or ϕ/θ, computed. For each curve approximately 20 observations were made. For each frequency tested a number of curves were taken, usually five or more, and the average value of ϕ/θ computed.

A second method of procedure was for the observer to adjust the phaser so that a certain angular displacement would be produced. A "random" selection of angular displacements was used. The phaser was located in a separate room and the adjustment made by a rod extending through the wall. The observer had no knowledge of the phase difference settings during the series of the 20 observations.

The accompanying three curves, Fig. 3, represent the computed values of ϕ/θ for three different observers. On the up-

[6] *Loc. Cit.*

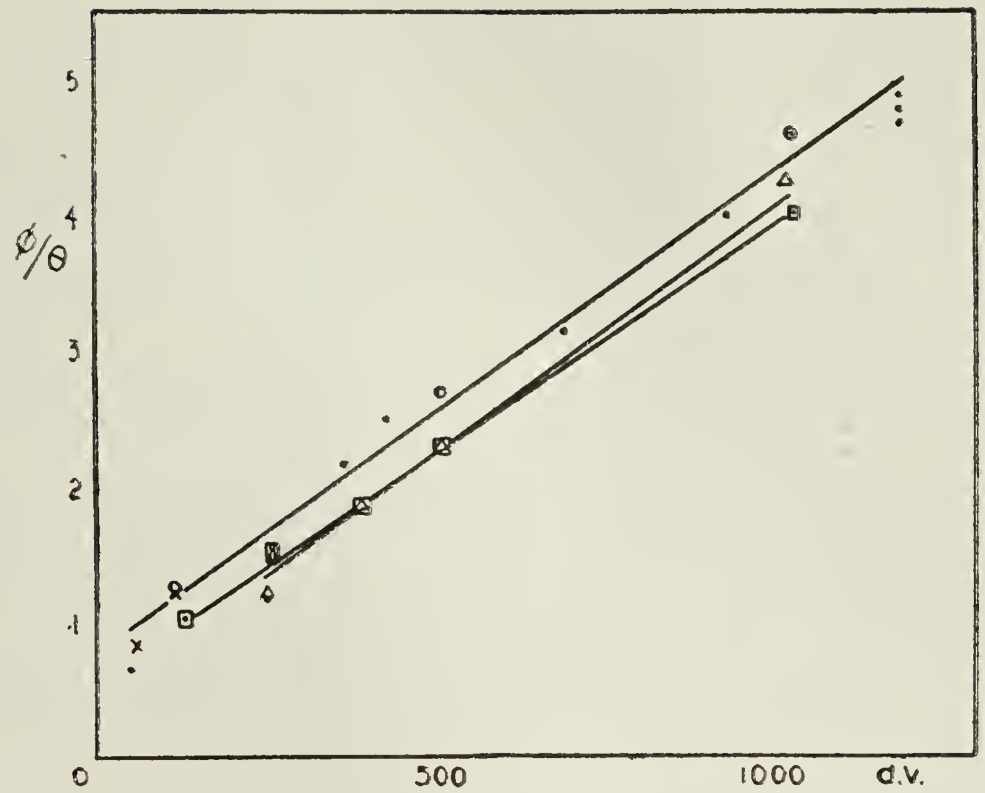

FIG. 3

permost curve the dots represent results with the phaser, and the crosses and circles tuning fork tests described in the earlier report already cited. The computed values corresponding to the other two curves are represented by squares and triangles. The observational values for the uppermost curve were secured by the first method described and the remainder by the second method. It is noticed that the second seems to give more consistent results.

Frequency limit of the phase effect. With the same apparatus measurements of the frequency limit of the phase effect was made upon 16 observers. The values of frequency recorded are only approximate having been made by a comparison with a monochord under constant tension, which had been standardized by a fork. The accompanying table shows the limiting frequency for each individual. Above this limit there was no rotation whatever of the fused sound about the head with any of the frequencies less than 2,000 d.v. that were employed.

There are two striking indications to be found in the table. The first is that the frequency is approximately constant, and second, that there are exceptional wide variations from the mean value. The average deviation from the mean is 155 d.v. Omitting two observers, it is only 110 d.v. This constancy has a dis-

Table I

E M B	1360 dv.
A E T F	1335
C K K	1119
H M H	1474
M L	1767
I K	1249
E S	1392
C R B	1333
S C	1161
E R K	1146
C E L	1058
R K	1145
G W S	1248
E G R	1151
A C R	825
G R W	1393
Mean	1260

tinct bearing upon the conclusion elsewhere derived[7] that phase difference is the most important factor in localization up to 1,200 d.v. Attention should be here directed specifically to the results of other observers upon the frequency limit. L. T. More[8] states that a fork of 512 d.v. is near to the limit where he possesses accuracy in the judgments conditioned by phase differences; that with 1,024 d.v. his judgment became untrustworthy and that with 3,000 d.v. he had no sense whatever of direction. Lord Raleigh[9] gives the limiting frequency of his right and left displacement judgments as 768 d.v. C. S. Myers and H. A. Wilson[10] state in general terms that with very high frequencies the lateral effects cannot be obtained.

Discussion of Results

It seems that the similarity of the values of ϕ/θ for three individuals, the only ones upon whom extensive measurements were made, would indicate the probability of no considerable variation for different individuals.

[7] Stewart, *Loc. Cit.*
[8] More, Phil. Mag. XVIII, 1909, p. 308.
[9] Lord Raleigh, Phil. Mag. XIII, 1907, p. 224.
[10] Myers and Wilson.

It is to be pointed out that if such a straight line as in Fig. 3, when extended, passed through the origin, it would indicate that θ, the angular displacement, is strictly proportional to the difference in time of arrival at the ears of a given phase, and that this is *independent of frequency.* This is seen to be true from the following:

We would have from the curves,

$$\phi/\theta = K \times f$$

where K is constant and f is the frequency. If one selects any time interval, Δt, and assumes the value of θ for each frequency θ to be so selected that the arrival of waves for all frequencies will differ as to time by the value Δt, then we have,

$$\text{Since } \phi \propto f \times \Delta t$$
$$\theta \times K \times f \propto f \times \Delta t$$
$$\text{or, } \theta \propto \Delta t$$

Or, in words, θ is proportional to the time-interval and is independent of frequency. It is obvious that Δt can be any time-interval and that therefore the statement is perfectly general. These considerations lead one to the conclusion that, approximately, the binaural difference of phase effect is quantitatively a time effect. But probably a more illuminating explanation is found in the author's earlier contribution.[11]

It was shown in that report that the experimental curves agree quantitatively with the conclusion that localization of pure tones ranging from 100 to 1,200 d.v. depends chiefly upon the phase at the ears. Or, to explain more fully, the computed phase difference at the ears when there is a source of sound at a given angular displacement from the median plane corresponds to that phase-difference which in these experiments actually produced that same angular displacement of the apparent source of the fused sound. In short, it seems that the binaural difference of phase effect has been evolved through experience. The author is not here concerned with the question as to whether this binaural difference of phase sensitivity is acquired by the individual or not.

[11] *Loc Cit.*

Concerning the limiting frequency and the small individual variation from a mean, our interest is aroused because it is not clear why such should be the case, even under the supposition that the phase-sensitivity herein discussed is chiefly responsible for the ability to localize with frequencies lower than the upper limit. Attention should be called, however, to the significant fact that the phase gives a *unique* location only when θ is less than 180°. According to the upper curve in Fig. 1, the value of Φ corresponding to $\theta = 180°$ at 1,200 d.v. would be approximately 36°. Since this angle, corresponding to $\theta = 180°$, diminishes with increasing frequency, doubtless the usefulness of the difference of phase must accordingly decrease as the frequency increases. But this explanation is not fully satisfactory, though it may become so when assisted by additional information to be acquired in the future.

Psychologists are familiar with the influence of intensity-difference upon localization and this phenomenon is subject to generally accepted principles. But the recognition of a phase-difference at the ears with the two intensities equal means, it would seem, a response to a different and more intrinsic feature of the stimulus. The suggestion that we have here to do with a response to the character of the stimulus will doubtless be regarded with skepticism, and an attempt will be made by some to explain the "phase-effect" in other terms. Indeed, this has already been attempted by Myers and Wilson[12] who have explained the phenomenon in terms of intensity at the ears, the alterations in intensity being occasioned by sound-conduction through the head and the fact that with changing phases incident at the ears, the combined intensity from the direct and cross-conducted waves is altered. There are several indirect arguments against the acceptance of such an explanation, but it has been the writer's good fortune to get what seems to be conclusive evidence that any explanation in terms of physical *intensities at the ears* cannot be correct. This evidence is direct and readily understood. It has been shown in Part I that with some individuals there are frequency regions or bands wherein the observers are not influenced in their localiza-

[12] Myers and Wilson, Proc. Roy. Soc., 1908, 80, p. 260.

tion by variations in the ratio of intensities at the ears, phase-difference remaining constant. With them, in this "lapse-region," the apparent source of the fused sound remains stationary in the median plane when the ratio of intensities is altered widely. But the significant fact is that with six of sixteen observers *the "phase-effect" is continuous in at least a portion of this lapse-region.* In short, the phase-phenomenon seems to be independent of the intensity displacement effect. The reader may see the evidence most distinctly in Figs. 1 and 2 of the preceding section wherein the single straight horizontal lines represent continuity of the phase-effect while the partially or fully blocked lines above represent the varying judgments of these observers with difference of intensity alone. The open space in the region between two lines otherwise connected either by a solid block or by separated vertical shading, represents the lapse in the intensity displacement-effect while the numbers at the top represent the frequencies employed. To repeat, the simple argument is that if a variation of intensity-ratio at the ears does not produce an angular displacement of the fused sound when these intensities are presented to the organ of hearing through the aerial route of the external meatus, then a variation in intensity-ratio secured by transmission through any other route to the same organs of hearing would likewise produce no displacement of the fused sound. It is obvious that the response of the organ of hearing to intensity-ratio would be independent of the manner in which that intensity-ratio was produced, or, in other words, independent of the route traversed by the sound-waves. It would therefore seem that any "intensity" explanation of the binaural phase difference-effect must be abandoned. It should be clearly understood by the reader that throughout this entire discussion, the words "intensity" and "phase" are used as purely physical terms.

A word may also be added to remind the reader that the author's experiments on phase and intensity have by no means furnished a complete and satisfactory explanation of the localization of sound. There is much information yet to be accumulated and probably some of it will require a close coöperation between physicists and psychologists.

Summary of Part II

This paper records the following facts obtained in regard to binaural differences of phase, herein called "phase effects":

1. The ratio of the phase difference at the ears to the angular displacement of the fused sound from the median plane is approximately proportional to the frequency of the pure tone employed.

2. This ratio is approximately the same for the three individuals upon whom extensive experiments have been made.

3. There is an upper frequency limit of the phase-effect, averaging 1,260 for 16 observers, the range of the tests being 200 to 2,000 d.v. Tests with one observer up to 4,000 gave no indication of a recurrence of the phase-effect, at higher frequencies.

4. The results upon the phase-effect, combined with earlier published results upon the effect of varying intensity-ratios at the ears show that the "phase-effect" cannot be explained in terms of intensity and that the organs of hearing must respond to phase as such, since phase and intensity are the only physical variations possible in a pure tone.

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MEASUREMENT OF ACUITY OF HEARING THROUGHOUT THE TONAL RANGE*

by

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Methods of testing auditory acuity—historical; the Iowa pitch range audiometer; procedure, discussion of cases, and conclusions.

Methods of Testing Auditory Acuity—Historical

The human voice. Of all the tests of auditory acuity voice tests have played the most important rôle from the sociological, psychological, and otological points of view. The ease with which such tests are conducted, their complete independence of mechanical contrivances, their significance from the social viewpoint, as well as their diagnostic value, have in part counterbalanced the impossibility of adequate standardization. Bentley says (6), "There is no doubt that human speech, could it be definitely controlled, would furnish the most adequate and most comprehensive means of determining auditory acuity." The report of the Committee of Otological Research of the Royal Society of Medicine for 1918 (12) states that

"A scheme for the tests of hearing was discussed and drawn up as follows: Conversational Voice—single words or sentences with the opposite ear closed. Distance from each ear expressed as a fraction with the distance at which voice is heard from the normal ear as denominator. Whisper —conditions as above, but whisper produced by residual air after forced expiration. It is recognized that the voice tests are approximate only, as it is impossible to devise an exact standard. The words or phrases to be recorded when possible."

The choice of the spoken or whispered voice is largely de-

* The writer wishes to acknowledge the help of those with whom he has been most closely associated in this study. Dr. C. E. Seashore suggested the problem and has offered every facility of the department for its successful completion. Dr. L. W. Dean gave his constant encouragement and assistance and made the diagnoses of the pathological cases which are presented. Prof. A. H. Ford gave much assistance in the design and supervision of construction of the apparatus. Prof. G. W. Stewart offered many helpful suggestions. Mr. J. B. Dempster, the departmental mechanician, by his skill and practical knowledge of construction assisted very materially in the work.

termined by the conditions under which the tests are conducted. If a large room is available, the spoken voice is usually preferred. This is particularly true in schools where, as a rule, sufficient space is available. The cramped quarters of the practitioner usually compel the use of the whispered voice. The value of the whispered word is usually considered one third that of the spoken.

Frequently the voice test is used without knowledge of its diagnostic value or nature and is exceedingly crude. The monumental work of Wolf (74) in determining the auditory values of the voice sounds deserves notice because of its scientific accuracy as determined by later investigation. Speech, according to Wolff, has a compass of five octaves, from C to c^5, the lowest sound being that of the lingual *r* and the highest the *s* sound. Different disturbances in the sound conducting mechanism of the ear are indicated by variation in the ability to perceive the tones in different parts of the musical scale. He divides words into three groups depending upon their pitch. Group 1 contains the acute and far reaching hissing sounds such as are present in the German word *Strasse,* and the acute sounds of low intensity such as the *f* in *Feder.* Group 2 are called explosive sounds, as *k* in *Kette.* Group 3 contains the grave sounds such as the lingual *r* mentioned above. In middle ear disturbances the patient will understand *Meter* for *Messer, Braten* for *Strasse,* etc. The consonant *m* sound is of diagnostic value only when whispered.

Gradenigo (19) gives the distances at which various voice sounds should be heard. He prefers the spoken word to the whisper test, especially with army recruits.

Zwaardemaker (78) says, "The lack of consistency in the results of testing aural acuity by means of whisper is seen in a new light if the choice of words is undertaken in a more systematic fashion." This writer has reviewed the work of Pipping (Finnish), Boeke (Dutch), Hermann (German), Sasswjliff (Russian), Verschuur (Dutch Dialect), Bevier (American-English), Stevani (Italian), and Delsaux-Quix (French) and divides the voice sounds into two groups, the *zona gravis,* or sounds of tho lower part of the musical scale from C to d^2, and the *zona acuta,* or treble zone, from d^2 to fis.[4]

Andrews (3) prepared a table which he thinks contains all the vocal elements of Wolff's series, has an equivalent number of elementary words, and gives relative prominence to the various classes of consonants. Unfortunately he does not attempt an interpretation of his results from the diagnostic viewpoint.

Kerrison (28) uses a table of spoken words consisting of seventeen columns of monosyllables, each column containing seven words beginning with the same consonant. In the first column are the words bad, bend, bed, band, bard, bold, bond. Beginning with the first word of this column the examiner is to pronounce the words across the list, the first word in each column, i.e., bad, cad, dab, fad, gap, hard, jag, lad, mad, nap, pad, rat, sat, tap, vat, wall, zeal, then the next line, etc., recording the words missed. He holds that ordinary words are unreliable. If numbers or polysyllables are used the patient quickly learns the sounds and is soon able to repeat them whether he hears the sounds distinctly or not. Because of the widely different values of the consonants in ordinary words a cue is given to the observer which helps with the sequence of the other sounds. Besides, the patient soon learns the vocabulary of the examiner.

A further approach in the direction of standardization of vocal sounds is made by those experimenters who attempt to produce the sounds of the voice by artificial methods. Marage (34) invented an acoumeter which produced mechanically the various vowel sounds. Robin (45) also devised a method of producing vowels mechanically.

It is now generally accepted that each vowel obtains its peculiar quality from the dominance of overtones at specific pitch levels. Miller (35) with the phonodeik, an instrument used for tone analysis, has determined that there are points of resonance for the various vowel sounds and that these points are constant for all voices. Any loss of hearing for a sound is thus accurately located in the musical scale. He found that these points of maximum resonance are as follows:

Vowel	ma	maw	mow	moo
Whisper	1019 d.v.	781	515	383
Spoken	1050	732	461	326
	mat	met	mate	meet
Whisper	857	678	488	391
	1890	1942	2385	2815
Spoken	800	691	488	308
	1840	1953	2461	3100

These results indicate that the tonal range between 326 d.v. and 3100 d.v. is most directly concerned in the determination of vowel sounds.

It is difficult to select any system and call it ideal. Each examiner has a series of words which give results capable of diagnostic interpretation. It is doubtful if examinations in different languages are comparable because of the wide differences in enunciation.

The phonograph. Bentley (6) attempted a standardization of voice tests by means of the phonograph. Two methods of controlling intensity were suggested, one by the use of a certain type of reproducer and the other by a sort of stop arranged in the rubber transmission tubes. Bryant (10) suggested that the sound from the phonograph be conducted to the ears of both the patient and the examiner by means of parallel rubber tubes. Bevier (7) investigated the quality of the tones from a phonograph. He analyzed the sound of the letter *a* and found that the quality of the tone depends upon the fundamental together with the first two or three overtones, the maximum being from 1000 to 1300 vibrations. The fact that the phonograph is not in use for tests of audition seems to indicate that it has not proved successful in practice.

Tuning forks. Bezold (8) says, "The separation of noises from tones long hindered the development of otology, because it gave rise to the idea of a separate region for the perception of noises outside the cochlea, in another part of the labyrinth." Having definitely established the reliability and accuracy of tests using tuning forks which give pure tones, the necessity of securing quantitative relationships between the thresholds for normal and diseased ears occupied the attention of otologists. v. Conta's principle of recording the results of fork tests as fractions, the numerator being the time in which the diseased ear was able to perceive the tones and the denominator that required for the "normal" ear, was offered in 1864. Ostmann (36), working with several forks in different parts of the musical scale, found that the rate of dying out varied in different parts of the scale. The principle suggested by Prout (39) in 1872 of comparing distances and recording the results in the form of fractions gives serviceable results, but the fractions do not indicate acuity values directly since the intensity of the sound varies as the square of the distance.

In 1834 Henry Scheibler (48) constructed a set of tuning forks, 56 in number, covering the octave between 440 and 880 d.v.

For the purpose of exploring the entire range of audible tones which seemed to be the next logical step, Koenig built his tonometer (30). This consisted of a series of carefully tuned forks, one hundred and fifty in number, which covered the tonal range between 16 and 21844 vibrations. In the description of this series of forks we find no report of an attempt to control the intensity of the tones either by a specially constructed striker or by any other device. The purpose was to secure qualitative rather than quantitative results.

Since the forks of Koenig did not reach the upper limit of acuity, Appun (4) constructed a series of eleven forks covering the range between 2000 and 50000 vibrations.

For general diagnostic procedure we find that most examiners employ a series of forks similar to that constructed by Edelmann and Bezold, presented in America by Knapp (29). The set is called the "Continuous tone series" because all the tones and half tones in the range of the forks may be secured by means of adjustable weights. The ten forks of the set do not cover the entire range of audible tones but are supplemented by three whistles, the highest being a modification of Galton's whistle. On account of the size of the adjustable weights, the tones emitted are quite free from partials. The forks as used by Bezold are not accurate because of the impossibility of controlling the strength of the energizing blow. The low forks emit very faint tones; more intense sounds are needed to determine absolute deafness.

Downey (14) devised a means of energizing the tuning forks used in tests of audition by regulating the distance from which a small weight fell against the prongs. The tones were carried to the ears of the observer through rubber tubes. Quix (40) divided the pure tones into three groups depending upon the distance at which the tuning forks, energized in a definite manner, could be heard.

In 1906 Behm (5) brought out his universal sonometer and a tuning fork sonometer. He entered into an exhaustive consideration of the difference between what he called the physiologic and the physical intensity of sound as determined by his sonometer.

On the more practical side several devices have been presented whereby an approximate measurement of the intensity of the sound may be made. Von Kittlitz (64) attached two thin plates to the prongs of a fork. The plate held nearer the eye of the experimenter is provided with a narrow slit through which the excursions of a white triangle on the other prong may be observed by means of a reading scale in a microscope. The excursion of the triangle when the fork produces a just audible tone is thus secured. Since the sound varies with the square of the amplitude records of the minimum intensity must be in terms of the squares of these amplitudes.

Gradenigo (21) energizes the prongs of tuning forks in a definite manner by means of a trigger attachment. Four different initial intensities are provided.

Urban (60) secured variations in intensity by turning an electrically operated fork so that he was able to secure interference between the sounds from the two prongs as sources.

Other sources of sound. The singing flame and electric arc have been widely used. Jastrow (26) thinks the singing flame is successful because it is possible to measure the amplitude of the vibration of the flame by microscopic methods and to secure records as to the quality and frequency by the photographic method.

H. Lichte (32) using the singing arc with frequencies between 220 and 846 finds that the sound intensity is proportional to the arc length and to the square of the alternating current strength.

Lucae (33) made a sonometer in which the pressure of the air accompanying enunciation impinged upon a movable diaphragm. The amplitude of the movement was recorded from the excursions of a small pointer attached to the diaphragm.

Urbantschitch (58) designed a harmonica to produce sounds of uniform strength by means of resonators of variable lengths attached to the instrument. Toepler and Boltzmann (62) used a comparatively loud sound from an organ pipe and after removing the observer to such a distance that the sound was just audible they computed the energy value for this tone upon Helmholtz' generalizations. Wolfe (75) proceeded in a similar fashion with the sound of a blown bottle. Webster (69) has designed an instrument called a "phone" for producing a constant sound and another, a "phonometer," far measuring the intensity of this sound in absolute units. Stern's (56) tone variators are based on the principle of the blown bottle. The siren is capable of producing a wide range of frequencies but has small possibilities for intensity variation.

The chief value of devices like those mentioned is limited to determining the residual hearing in very advanced cases of deafness.

Noises. The inability of experimenters to secure accurate control of the intensity of the sound produced by tuning forks and the other devices mentioned above has led many to attempt the construction of an appliance which would produce a noise that might be of standardized intensity and quality. Because of the immediate availability of the watch, it has been a common means for measuring hearing ability. The Society for Otological Research (12) quoted above, recommends the watch in addition to the voice and the Politzer acoumeter (38).

In the instruments presented by De Bechterew (13), Wundt (76), Lehman (31), Sanford (46), Kampfe (27), Henry (24), and others, the principle of the moving pendulum is adopted. A small weight attached to the pendulum may be raised to different heights. In falling the weight strikes a small cylinder of steel at the bottom of the arc. Gradenigo (20) uses this principle and has cylinders of various sizes which give tones of varying pitch. Amberg (2) uses a freely falling body which strikes against a metallic block. Toulouse, Vaschiede and Pierron (61) substitute a falling drop of water for a solid body.

Electrical devices. The sonometer by Hughes (25) was one of the first in which an attempt was made to secure accurate control of the intensity of the sound in the telephone. He used the principle of the sliding inductorium and established a zero point by using two opposing primary coils. For producing a tone Hughes used a Neef's hammer. The acoumeter described by Urbantschitch (59) is similar in construction.

Stefanini (53) used but one primary. Seashore (51) varied the intensity in his audiometer by using a graded series of secondary coils over a stationary primary with the telephone. The increments for the forty steps of intensity are made psychologically equal in accordance with Weber's law. To produce a tone a tuning fork of desired pitch is operated in the primary circuit.

Campbell (11) reports a simple alternating current generator which will produce a small current of pure sine wave form. It consists essentially of an electrically operated tuning fork to one prong of which is attached a small coil with its axis parallel to the prong. When the fork vibrates, the coil oscillates in the field of an external magnet. An oscillating current is in this way induced in the coil attached to the prong.

Rayleigh (41) produced a current of harmonic type by rotating a magnetized watch spring in the field of a strong coil in series with a telephone. The magnet was fan-shaped and rotated at a uniform speed by means of a steady air blast.

Stefanini (55) modified the method of the pendulum to produce a pure tone by electrical methods. The weight of the pendulum was a small arc of soft iron composed of several uniform teeth. As the pendulum fell, the arc of iron was carried through the field of an electric magnet in series with a telephone. The magnetic variations caused by the passage of the iron teeth through the field, induced an oscillating current of momentary duration in the telephone circuit. The tone varied with the number of teeth, their size, the rate of fall, and the original impulse as well as with the distance from the magnet to the path of the falling arc.

The field of hearing

The field of hearing based on a time ratio of audition for the different tuning forks has been illustrated by various writers.

The fields of hearing illustrated by Grant (22) are based on measurements with five tuning forks. That illustrated by Pfaundler and Schlossman (37) is for fourteen forks. The extent of such measurements is usually determined by the amount of time the investigator wishes to spend in making the examination. It is quite common to find only three forks used, one for low tones, one for those in the middle of the musical scale and one for the higher tones. Tone gaps or defects in the field of hearing lying in the regions between these forks will not be noted, and to that extent these representations are misleading.

The field of hearing by Wien (71) was secured by means of a telephone, the low tones being secured by an inductor and the higher ones by an alternating current siren. After measuring the current necessary to produce a just audible sound, the actual energy was calculated and the curve drawn on the basis of this calculation. No attempts were made to explore either the upper limit or the lower. Four types of telephone receiver were used in order to show any peculiarities which might occur in the instruments themselves. Any irregularities appearing in the curves may possibly be accounted for by the differences in construction of the instruments, the different natural frequencies of the diaphragms, or perhaps by fluctuations in attention during successive tests.

The lower limit. The lower limit of tonality is placed by various writers at from 8 to 16 d.v. There is no sharp demarkation in the passage from individual puffs to a continuous tone. Indeed, the two overlap. The individual puffs can be heard up to 20 or 30 v.d. Under most favorable conditions, the tonal quality is clear at 12 d.v., but ordinarily it is not heard lower than 14. The limits set vary with the intensity, duration and timbre of tone. Vance, who has made the most valuable investigation of this subject (63), has shown that, in terms of a sounding instrument, such as the tuning-fork, the principal conditions are essentially the amplitude, the size and shape of the disk, its proximity to the ear, its position before the ear, the length of time it vibrates, and the form of the vibration. In making the measurements, we aim to select the most favorable conditions and to control these by keeping them constant. Thus, the standard procedure would maintain a fork with a 10 cm. disk, vibrating for five seconds, for the amplitude of 10 mm., the center of the disk being as close to the opening of the ear as possible without touching the lapel of the ear.

The upper limit. The determination of the upper limit of tonality is yet an unsolved problem. Since the work of Galton (18) many devices have been constructed for the production of tones of high pitch. The Edelmann form of the Galton whistle is still largely used. In using the whistles care must always be taken to exclude the possibility of mistaking the rush of the air for the shrill whistling sound. One may easily check the results by grasping the mouth of the whistle between the thumb and finger so that the air column cannot vibrate. Only the rush of the wind is then audible. Koenig made a series of forks which were said to reach as high as 90,000 s.v. He found that for himself the upper limit was lowered with advancing age. At 41 he was able to hear to 23,000 d.v. while at 57 he could only hear to 18,432 d.v.

Schwendt (49) used the Kundt's dust tube method for determining the actual pitch of tones near the upper limit. He found the upper limit with Koenig's bars to be 20,480 d.v.: with Koenig's tuning forks 21,845 d.v.; with Galton's whistle 21,845 d.v.; and with the Edelmann modification of the Galton whistle 27,361 d.v. He found that the frequency of G^8 of Appunn's series of forks was between 10,000 and 11,000 d.v. instead of 50,880 s.v. for which it was calibrated. He says instruments have not been made which will produce 40,000 d.v. and tones of that frequency cannot be heard.

Schulze (47) thinks that no matter what the intensity may be the upper limit is the same, namely, 20,000 d.v. This differs radically from the results obtained by Scripture (50) who, using the Galton whistle and air pressure of known values, found that the upper limit increased almost proportionally with the pressure. These and other discrepancies lead Hegner (23) to think that the Galton whistle should not be used for hearing tests. He recommends that the monochord of Schultze as modified by

Struycken (57) be substituted for the Galton whistle since it is much more reliable. Helmholtz speaks favorably of the monochord because of the possibilities of securing observations of the perception of tones by bone conduction. The tones of the lower octaves secured by transverse vibrations and the high tones secured by longitudinal vibrations make the instrument useful for securing results throughout a considerable range. The high tones on the monochord are very faint and may be mistaken for the rubbing of the sponge against the wire. This may be checked by rubbing it against the steel frame. The applicability of the instrument for testing perception by bone conduction is a point in its favor in certain pathological cases.

Birnbaum (9) has used a telephone with some success and thinks that the upper limit is about 25,000 d.v. As stated before, the telephone with its immense number of turns of wire offers great impedance to very high frequency currents so it is doubtful if very intense tones near the upper limit of audition can be secured. Some experimenters find that the telephone is ruined by the heat of the current which is necessary to produce tones of high frequency.

All of these instruments have been available for comparison in the present study, but their calibrations have not been checked by physical measurements. The writer finds that at the age of 35 he can hear tones calibrated on the several instruments as follows: 49,000 s.v. (24,500 d.v.) with the Galton whistle, 49,152 s.v. with one set of cylinders, 40,960 s.v. with the other, and with the monochord 19,000 d.v. by air conduction, and 20,000 d.v. by bone conduction.

The acoustic macula. Rayleigh (43) measured the actual intensity of the sound reaching the ear from a body vibrating at a distance. The sources used were cans vibrating as bells. These were energized electromagnetically in order to eliminate accessory noises. If the energy necessary to produce an audible tone at a frequency of 512 d.v. is taken as unity, the ratios for the various frequencies are as follows:

Frequency	Ratio
512	1.0
256	1.6
128	3.2
85	6.4

No attempt was made in this series of experiments to determine which frequency has the minimum threshold but Rayleigh thought it would not be reached under 1024 d.v. or perhaps not until an octave higher.

Abraham (1) varied the experiment by measuring the air pressure produced by the vibrating telephone membrane and concluded that for a normal ear, with frequencies between 250 d.v. and 500 d.v., the pressure necessary to produce an auditory sensation was 0.0000004 mm. of mercury.

Rayleigh (44) also made a calculation of this nature and found that a condensation of 4.6×10^{-9} ergs at a frequency of 512 d.v. was sufficient to produce an audible tone. Zwaardemaker and Quix (79) found that 1.3×10^{-5} gave an audible tone while Wead (68) found it to be 1.1×10^{-8} and Wien (72) placed the value at 612×10^{-8}.

By means of his electric micrometer, Shaw (52) measured the amplitude of vibration of the telephone receiver for the minimum impulsive sound caused by a break in the circuit. He found that an amplitude of 0.4 $\mu\mu$ was just audible, 50 $\mu\mu$ comfortably loud, 1000 $\mu\mu$ uncomfortably loud, and 5000 $\mu\mu$ overpowering. His threshold of audibility is calculated since he was not able to measure distances less than 2.1 $\mu\mu$.

Franke (17) used the optical interference method and decided that 1.2 $\mu\mu$ gave the least audible impulsive sound. He secured measurements to 52 $\mu\mu$ and assumed a straight line relationship between the origin of his curve and the limit of measurement in calculating the minimum audible sound.

The general trend of opinion of experimenters using tones which cover a wide range in the field of hearing seems to indicate that there is a region of greatest sensitivity. It has been shown in pathological cases that this region actually resists the ravages of disease or trauma better than the remainder of the field. Wilson (73) in all cases of shell concussion, finds not only a diminution for all tones in the field of hearing but also the least decrease in sensitivity for tones between 512 d.v. and 1024 d.v. Wells (70) in studying the effects of fatigue has shown that the tones in the middle range are least liable to fatigue and that the lower and higher tones are especially susceptible to it. Rayleigh (42) had previously noted the extreme liability to fatigue for tones in the upper part of the tonal range. Wead, however, (67) concludes that, independent of the intensity of the tone, within experimental limits the sensibility of the ear is the same for tones of every pitch. Stefanini (54) subjects his findings to severe criticism. Wolf (74) in discussing the same point says, "The normal ear is most sensitive to the most acute tones of speech so that those tones which lie in the middle portion of the fourth octave and approach the proper tone (resonating frequency) of the auditory canal and membrani tympani (e^4 to g^4) may cause, under certain circumstances, the sensation of pain. The faintest pianissimo of the violin up to e^4 is distinctly heard in a large hall to the last seats. I believe that the fibres of the zona pectinata which vibrate in unison with the most acute tones, are the smallest and most delicate." Wien (71) and Zwaardemaker and Quix (79) have shown results indicating the same region of extreme sensitivity which, according to the findings of Miller, is in the region covered by the sounds of the human voice.

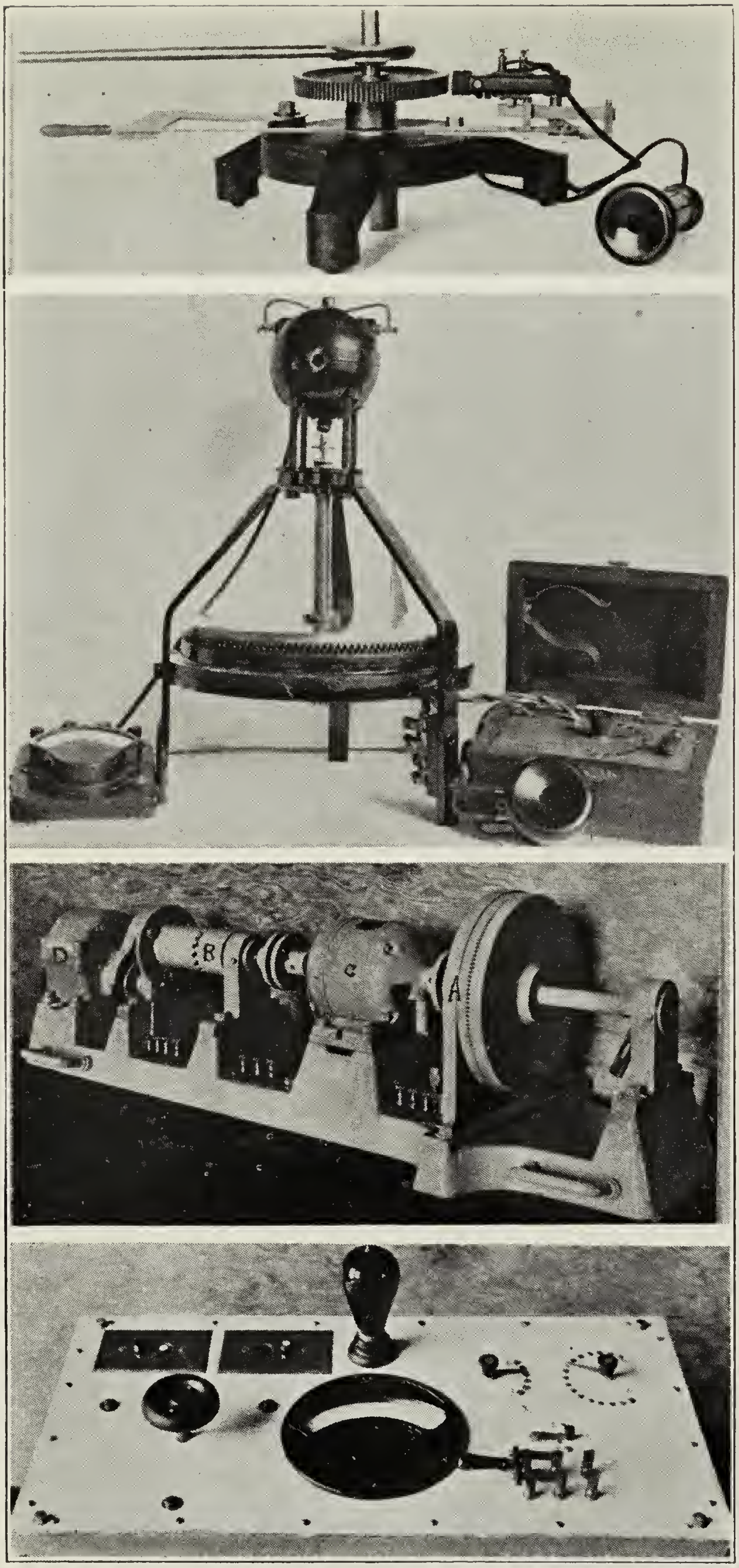
Wanner (66) concluded that the ear was deaf for speech if it was unable to hear the a^1 tuning fork by aerial conduction. Zwaardemaker (78) places the region in the zone from a^1 to e^3.

So far as we have been able to determine, there is in the cochlea no specialization of structure to account for this region of maximum sensitivity. The almost universal agreement on the part of investigators leads us to think that any acceptable theory of hearing must account for its presence. The results given in Chapter III of the examination of the effects of the various auditory lesions adds evidence on this point.

The Iowa Pitch Range Audiometer

The present demand of examiners is illustrated by the Bezold continuous tone series referred to above. Determination of the limits of audition in particular regions is not sufficient; it must be possible to ascertain the threshold of audibility for any or all tones. The Bezold series offers an accurate control of quality but not of intensity. A series of adjustable length organ pipes, a piano, a complete series of tone variators, a monochord, a vibrating flame, or any instrument capable of producing a wide range of frequencies would answer the same purpose save that the intensities would be less in control and the wave less harmonic in form. The use of a large number of forks or pipes in tests is impossible from a practical consideration if for no other reason than the amount of time and energy consumed. The ideal test should be of such a nature that the sensitivity of the ear throughout the entire range of audible tones could be quickly and accurately determined. The tones must be relatively pure. Quantitative measurements may be in either relative or absolute terms. The test must be capable of standardization, require a minimum of time, be capable of instant verification, and require a minimum of skill on the part of the examiner. To meet these conditions, we have designed a new pitch range audiometer. A brief history of its development will be of interest to other experimenters in this field.

Duddell (15) constructed a high frequency generator of very simple form for work in wireless telegraphy. The fundamental parts of the generator were a toothed wheel rotating in a magnetic field. The rotation caused variations in the magnetic flow across the air-gap between the magnet and the teeth of the notched wheel, which in turn induced an oscillating current in a coil surrounding the magnet. With this type frequencies as high as 120,000 per second were secured. This generator was used only for wireless telegraphy. The current generated was of considerable magnitude and little consideration was given to the current wave form. The generator constructed by Rayleigh (41), as described above, would serve for generating tones of a considerable range of frequencies but the current would be small and the resulting tones would probably be too faint for clinical use. The necessary air pressure for rotating the magnet limits its utility since a means of producing this pressure is not always available. Slight variations in the form of Stefanini's generator (55), described above, would make it possible to produce a considerable range of frequencies for tones of short duration. A



a

b

c

d

Fig. A.—The Iowa Pitch Range Audiometer: a, first model; b, second model; c and d, fourth model.

mercury lamp of the type used in the Vreeland oscillator (65) would, by a suitable arrangement of capacities and inductances, provide a wide range of frequencies but each frequency requires a different inductance and capacity with the accompanying electrical connections. This would be true also for any of the various types of vacuum tubes now so commonly used in wireless telephony and telegraphy. For practical use in the hands of one unskilled in the use of complicated electrical apparatus this type of generator, while offering many advantages for this study, seemed inadvisable. Gradenigo (19) has a vibrating metallic ribbon for producing an electrical current of low frequency but of very pure wave form. The frequency of the oscillating current must always approach that of the vibrating ribbon. When used with a telephone the sound is much more intense than that obtainable with the low forks.

Development of first type of generator. In the present enterprise a Leeds-Northrop Generator No. 39226 was first examined. It consists of a motor with an attached notched wheel. As the motor rotates, the teeth of the wheel pass through the field of a horse-shoe shaped electro-magnet. The speed of the motor was constant except for the possibilities of slight adjustment with the governor. The pitch of the tone produced was approximately 1100 d.v. per second. However, as the machine slowly gains momentum, a range of tones between the lowest audible tone and the maximum (1100 d.v.) could be heard in the telephone. When driven by an independent pulley attached to the shaft and connected to an adjustable speed motor, it was possible to produce and maintain with fair constancy any tone within these limits.

In order to approach more closely the ideal test requirements, it was necessary to secure a much wider range of frequencies than that provided by this generator. For preliminary trials a cast iron gear wheel 6 inches in diameter, with 96 teeth, No. 16 B & S gauge, was mounted on the shaft of a variable speed motor. (See Fig. Aa.) After grinding the wheel so that the radius was constant, a bipolar magnet from a hand-type telephone receiver was mounted so that the teeth of the gear-wheel passed through the magnetic field. The two coils at the extremities of the magnet were connected in series with a telephone. Preliminary tests showed that the quality of the tone produced by this generator was relatively pure, that the intensity was adequate, and that a range of speed between 2 and 100 revolutions per second was available. With the 96 teeth on the gear-wheel, pitches between 200 d.v. and 10,000 d.v. should have been available for our work. However, as the speed of the motor increased, 35 rotations per second produced not only the tone due to the passing of the teeth before the magnet but also an accessory tone corresponding in pitch with the rate of the rotating armature and of an intensity disturbing to the observer. For tests up to and including 3100 d.v. per second the tones were sufficiently pure so far as indicated by psychological observation. No method for determining the character of the wave form was available. An oscillograph would analyze only currents of much greater magnitude. But observers experienced in the field of acoustics were unable to determine the presence of overtones when the intensities were moderate. The similarity between the tones in the receiver and those from tuning forks was remarkable. But as the telephone diaphragm has peculiarities it is not probable that the tones were absolutely pure.

The use of the telephone in tests of audition is subject to criticism because of the great variation in the different types. It is probable that no two telephones are identical.[1]

During the early part of this study, one watch case type of receiver was used over a considerable period of time. Any

[1] A personal letter from the Research Department of the Western Electric Company concerning this subject contains the following: "The hand type telephone receiver equipped with a permanent magnet as exemplified in our standard 144W receiver is very constant over considerable periods of time. The magnet will not weaken appreciably unless subjected to very severe demagnetizing currents in the receiver winding, and even then will not be affected to any great extent. More or less trouble has been experienced from weakening of the magnets of most designs of watch case receiver on the market and in general, it would hardly be advisable to use this type of receiver where extreme constancy is desired. It has been our experience that hand type receivers will however be unchanged for periods of several years. We have no evidence indicating any particular limits to the life of the magnet of such an instrument."

hearing test that we could devise failed to show any appreciable change in its efficiency. It was abandoned after the above letter was received in favor of one of the standard 70 ohm hand type. As to the possibility of interchanging receivers, a test of six receivers of the same type and age showed that there were differences in the curves given in hearing tests with an experienced observer, these differences were less within one series than those which came from several tests with the same receiver due to the fluctuations in attention or changes in the physical condition of the observer.

Intensity variations. Four varieties of electrical control of intensity were tried. a. A lever arrangement varying the distance between the teeth of the rotating wheel and the magnet provides a mechanical means since the magnetic flux varies inversely with the distance across the air gap. (See Fig. Aa.) b. An audiometer of the Seashore model (51) provides a simple electrical method but the nature of the instrument is such that it necessitates the installation of a high impedance in the generator circuit because of the inductive winding of the primary coil. The high impedance of the magnet coils reduces the intensity for high frequencies very materially and the coils of the audiometer would cause a still greater decrease. c. High non-inductive resistances mounted directly in series will also decrease the current in a direct ratio but the production of tones of the magnitude necessary for the determination of the threshold of sensitivity would require enormous resistances with the consequent prohibitive cost. d. The phonometer,[2] a type of potentiometer designed by Ford, a much more feasible method of securing the necessary intensity variations. A series of non-inductive resistances with approximately 400 per cent increase in the successive coils and a total resistance of 1200 ohms is installed in series with the generator. Between successive resistances, terminals are provided for the telephone connections. The amount of current passing through the telephone is determined by the potential drop across

[2] A detailed description of the phonometer has not been published. The instrument was designed for use in telephony by Professor A. H. Ford of the College of Engineering.

its terminals. Thus if the telephone is in parallel with a high resistance, a large current will pass through it. If no tone is desired, the drop across the terminals should be reduced to nil.

Accessory sounds. The problem of eliminating the accessory sounds mentioned above was next attacked. The range provided was not adequate. The extension of this range necessitated the reduction of all accessory noises to such an intensity that they would cease to be a disturbing factor. The sound which caused the disturbance in this case apparently came from the rotating armature of the motor. A shield of soft iron was built about the gear-wheel to protect it from the magnetic field of the armature. This failed to eliminate the disturbing sound. The wheel was next removed from the shaft of the motor, mounted on separate bearings and driven by a belt as shown in Fig. 2. Tests showed the presence of the same disturbing sounds.

Two factors were not under control, viz., the bearings and the metal of the wheel. The assumption that some of the accessory tones were caused by inequalities in the structure of the cast iron wheel proved to be true. A twenty inch wheel of the spoked type was mounted in the bearings used before. Tests showed not only the presence of the original disturbing sounds but also another which corresponded in frequency with the rate at which the spokes of the wheel passed the magnet. The increase in mass at the junction of the spokes and rim causes unequal rates of cooling with consequent differences in the molecular structure.

Next a twelve inch plate of quarter inch boiler iron was cut into a wheel with 500 teeth. It was thought that a rolled metal would be more nearly uniform in structure than ordinary cast iron. When this was tested the telephone showed the presence of the same accessory noises. It was evident that the metal must be more uniform than any that could be secured by the process of rolling. Some cast iron plates were ordered from the foundry with instructions that the mixing and pouring be done with as much skill as possible in order to secure uniformity throughout. Three of these plates were discarded before the teeth were cut because of the presence of obvious inequalities in the form of blow holes. A fourth appeared to be without flaws. This was annealed, cut to shape, ground accurately, and 150 teeth were cut in the rim. The same disturbing sounds were still evident. In addition to this defect, because of the internal tension, the wheel warped three thousandths of an inch over night. An impulsive sound in the telephone indicated the presence of this exaggerated inequality each time it passed the magnet. If the speed increased, this became a tone of the same frequency as the rate of rotation.

The next step in construction was to build up a laminated wheel of rings of armature iron. The thickness of the rings was first accurately measured and the grain of the metal examined and alternated in successive layers. After grinding the circumference, 150 teeth were cut and the wheel was carefully balanced on its shaft. When the wheel was mounted and tried it was as unsatisfactory as those constructed before.

A plate of billet steel nine inches in diameter and one inch thick was next prepared. Members of the mechanical engineering staff assured us that this would probably be the best means of securing uniform metal. After cutting the plate to the required dimensions but before cutting the teeth, the circumference was ground so that no inequality in the surface greater than .0025 inch existed. Before removing the plate from the lathe a magnet was mounted. When the lathe was started slowly, impulsive tones were heard in the telephone which was connected to the mounted magnet. Increasing the rate of rotation caused the impulsive sounds to blend into low tones. Because of the presence of chatter marks made in the plate by the cutter, it had previously been decided that these marks indicated a spot which was not uniform. The test with the telephone seemed to justify this conclusion.

After these experiments had been tried and found unsatisfactory, it was concluded that it would be impossible to secure metal of such uniformity as the work demanded. A radical change in construction was demanded.

The second type of generator. (See Fig. Ab.) Our previous work had shown us that uniform metal could not be secured.

Therefore a generator had to be constructed which would render such inequalities ineffective. We adopted the plan of using as many magnets as there were teeth in the rotating wheel. Under these conditions, should there be any inequality in the iron, there would be no sudden approach of this part to any one magnet as it would be in the same relationship to all the magnets.

A rim was cut on the lateral surface of the plate of billet steel just mentioned and 140 radial teeth were cut in it. Eight thousandths of an inch away and parallel to this a stationary plate of cast iron was placed which was similarly cut with 140 radial teeth. This also served as a seat for a bearing of the rotating wheel.

Each tooth of the stationary plate was wrapped with ten turns of insulated copper wire. The plates were formed into a U-shaped magnet by placing a heavy coil between them and about the shaft. Upon trial, a receiver connected in series with the coils about the teeth gave no evidence of accessory sounds. The tone was, however, too faint to use in cases of extreme deafness. The number of turns about the teeth was increased to twenty-five without producing sufficient intensity. To double the windings would mean an increase of four times the current, but estimates had indicated that the tone should be from ten to twenty times as loud. To take 250 turns about each tooth was not possible because of the narrow space between the teeth. Either the form of the teeth had to be altered or some other arrangement provided for the coils. Therefor a coil of 300 turns was inserted between the plates as a secondary to the magnetizing coil. This was easily wrapped, was not liable to become short circuited by scratching the insulation against the sharp teeth, and was found to produce excellent results. But the tone was still too faint for our purpose. The coil was removed and another of 3,000 turns installed in its place. This with the adjustment provided for varying the air gap proved adequate.

Measurement of frequency. The earlier types of generators which had been constructed were not provided with any method for determining the frequency other than an approximation based on the position of the rider on the rheostat of the adjustable speed motor. This varied greatly with the external load. A more accurate method was desirable.

The stroboscopic method, as later more fully developed by Zuehl (77) was attempted. A disk of cardboard with a regular arrangement of circular holes was attached to the rotating shaft. A similar disk was mounted on a uniformly rotating plate situated below the first one. The experimenter, by observing the row of holes which apparently stood still on the lower disk was able to determine the rate of rotation of the upper one. This method was found to be inexpensive but rather complicated matters since it necessitated the use of an additional disk rotating at constant speed.

The Frahm type of frequency meter, an instrument of the vibrating reed type, was available but a special model covering the range desired would be so expensive as to be prohibitive.

Several types of magnetic and centrifugal tachometers are on the market but these do not offer possibilities of removal to any great distance from the generator which experience has shown to be extremely desirable. The electric tachometer, a form of which is shown mounted at the top of the tripod in Fig. Ab, consists of a small generator. Since the voltage with this type of generator varies with the rate of the rotation, a voltmeter which is attached was calibrated in vibrations per second and the frequency ascertained at once. It is also possible to remove the voltmeter to any required distance.

With the machine shown, frequencies as high as 7070 per second were obtainable. This was the speed limit of the loaded motor. Tones as low as 30 d.v. per second could be secured by means of a light brake on the rotating plate. The charts shown later which cover this range, were made from tests using this type of machine.

The third type of generator. The range of frequencies given (30 d.v. to 7070 d.v.), while offering much greater opportunity for examination and diagnosis than the type formerly used, was deemed inadequate for the present purposes. The belt driven generator was very inconvenient. It was highly desirable to have the experimenter located in the room with the observer.

This was obviously impossible where it is necessary to use a mechanical brake to secure the low frequencies.

To eliminate the belt drive and secure the low frequencies, a small generator similar in construction to that already in use except that the teeth were fifteen in number, was attached to the top of the rotating plate of the generator. Coils similar to those used in the large plate were inserted. A switch determined the plate to be magnetized. Another threw the desired generator in series with the telephone. Since the lowest speed obtainable was two rotations per second, the fifteen teeth in the small wheel gave a low limit of 30 d.v. Before attaching this double generator directly to the motor, a belt was attached and the arrangement tested. The residual magnetism in the small plate when once magnetized caused fluctuations which were carried to the telephone when only the large wheel was in series with it. This caused a second tone in the telephone. It was therefore evident that the direct attachment of the two generators was impracticable.

The fourth type of generator. Fig. Ac illustrates the design finally adopted. Generator A which produces high frequencies (to 15,000 d.v.) has a rotating wheel of billet steel nine inches in diameter, with 150 teeth cut radially (No. 8, 24 pitch, B & S involute gear cutter). The stationary plate is of cast iron and the radial teeth match those of the rotating wheel. The bearings are adjustable in all directions and wick oiled.

The generator for low frequencies, B, (30 d.v. to the lowest frequency produced by the large generator) is of cast iron cut with fifteen teeth (No. 7, 10 pitch B & S involute gear cutter), two cuts being necessary to make the spacing between the teeth vary by the width of the teeth. The bearings in the small generator were Radax No. ND 12, New Departure single row ball bearings.

The motor, C, is a Westinghouse ⅛ H.P. compound, 110 volt, D.C., with a speed of 1750 R.P.M. This was rewound to give the motor a speed of 6000 R.P.M.

The electric tachometer, D, is type M 200 F by the Electric Tachometer Corporation of Philadelphia.

Both the primary and secondary coils of the large generator have 3000 turns. The primary coil is of No. 28 enameled wire and the secondary of No. 36 double silk wrapped wire. The coils of the large wheel are fixed in beeswax and held in place by strips of brass. The two coils of the small wheel have 4000 turns each, the wire being the same size as that used for the large wheel. The coils are wrapped on a split spool of brass which is held in place by friction.

The whole is mounted on a cast iron base. This continuous base makes it possible for the mechanical vibration of the motor to be conducted to the high frequency generator. On this account the tone becomes slightly impure for the very high frequencies, and special instructions must be given to the observer if it is desired to test with these tones.

The control board, Fig. Ad, is of ⅜ in. asbestos board bound with angle iron to afford rigidity and attachment for the uprights. On it are mounted the following: (a) starting switch for motor, (b) rheostat, (c) tachometer scale, (d) signal light, (e) switch for telephone, (f) triple contact battery switch, (g) resistance control.

The tachometer scale is that of a Weston millivolt meter calibrated in vibrations per second. The meter is mounted beneath the board.

Procedure, Discussion of Cases and Conclusions

Procedure. The technique of the tests is simple. The board on which the control apparatus is mounted is placed in a quiet room so that outside noises will not disturb the attention of the observer. The receiver is held at the ear of the observer and he is instructed to indicate by some noiseless method that he hears the sound. For convenience we have used an electric key and lamp. The patient presses the key and lights the lamp as long as he hears any sound. If a check is desired, a switch leading to the telephone is opened by the examiner. Two methods of making determinations are possible. One, which is very similar to the method used with the tuning forks, consists in adjusting the speed of the driving motor so that a certain fixed tone is produced. The intensity is then diminished until the tone is no longer audible. This method offers several advantages over the tuning fork tests. It gives greater accuracy as to quantitative values, the results may be checked without loss of time, and no long wait is necessary to determine the damping time of the fork.

A new and much more comprehensive method has been developed. By this method the intensity is fixed at a certain resistance step and the pitch of the tone is changed. When all the audible tones at this intensity step are determined, the next fainter step is produced and the audible sounds at this step are determined. This process is repeated until only inaudible sounds are produced. With this method loss of acuity for any tone will be noted as the pitch gradually changes.

The results are conveniently indicated on a chart with pitch or frequencies as the ordinates and the intensity steps as the abscissas. The points at which the observer begins and ceases to hear are recorded by dots on this chart. When the examination is completed, these dots are joined in a curve indicating the field of hearing. Comparison with a normal curve on the chart reveals any variation from the normal. In this procedure, no tones are passed over untested, the results may be checked without loss of time and each test at decreasing intensities is an additional check on previous tests. A sound of continually changing pitch is much easier to follow and is consequently less fatiguing than one in which intensity alone is changed. The time consumed is much less than with the other method if one considers the amount of information secured. In practice the time consumed has been about fifteen minutes for both ears. If the mentality of the patient is below normal or if the findings are such that constant checking is necessary, a longer time will be required.

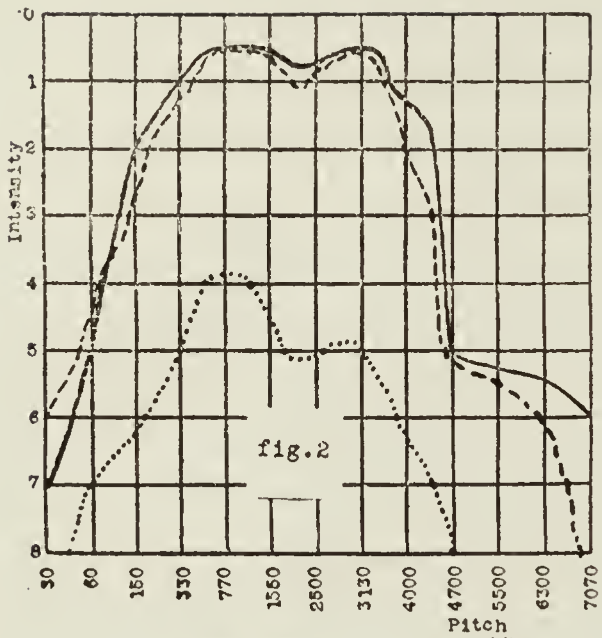
The chief work of the writer has been the development of the mechanical details of the audiometer. As the development of the machine progressed, one type was always in use and tests were carried on throughout the whole period. With the several types of machines different forms of graphic record were developed, as will be observed in the figures which follow. Since the work was largely concerned with the clinical significance of the tests, the charts given will be those selected from clinical cases. In each case, other clinical tests have been made and a diagnosis has been given by Dr. Dean and his assistants.[1]

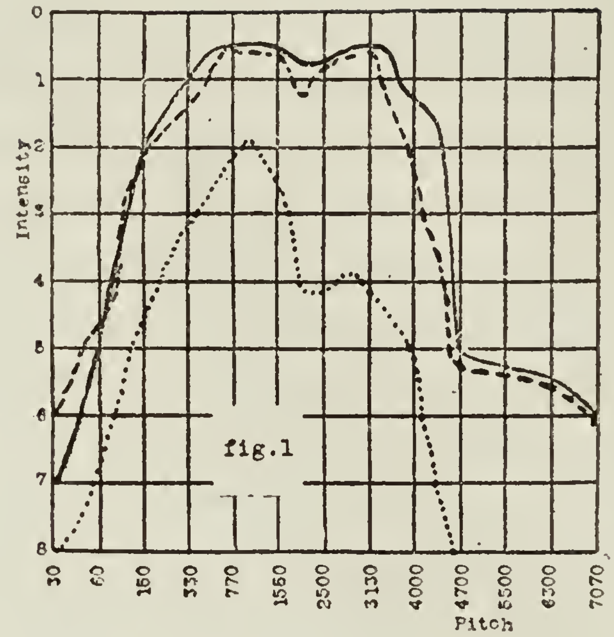
The clinical picture is without significance unless a normal curve is provided. In the charts which follow, normal curves are indicated by the unbroken lines. These normal curves were not worked out with extreme care as to age and general condition. It was neither desirable nor possible to make a survey of a large number of cases of all ages and send them to the clinic for the routine tests. With the first design of the apparatus a norm was secured by averaging the results of the best eight of thirty S.A.T.C. students. In the second, the norm was secured from tests given in the same manner to twenty-five university music students. In the third, it was secured from examination of adolescents and young adults who were known to have clincally perfect hearing and who were available in the clinic for hearing tests. Detailed results of these tests are not given. The norm indicates only the average of the best cases and is tentative.

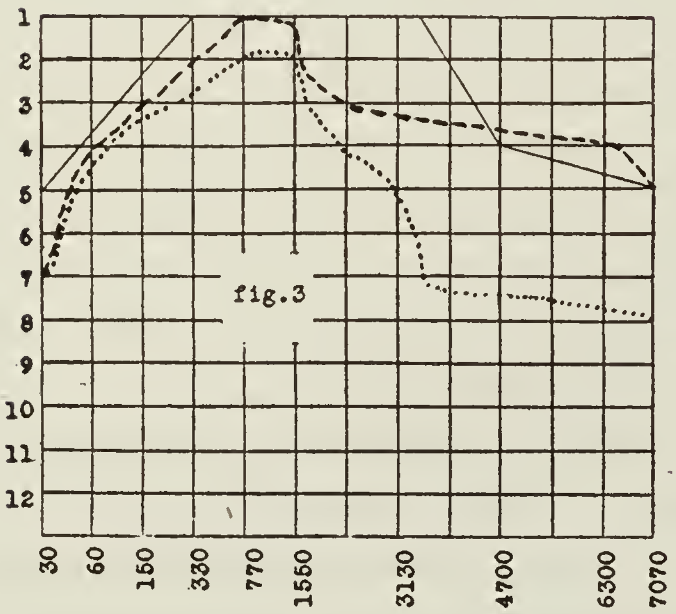
In the earlier work, an attempt was made to determine a "normal" curve for various diseases. As the work progressed, it became evident that such a finding would be impossible because the relative development of the disease would determine the general contour of the curves given. However, it soon became apparent that certain types of disease gave curves very similar in shape but varying in height on the chart and it was evident that the general profile rather than the height was the principal diagnostic feature.

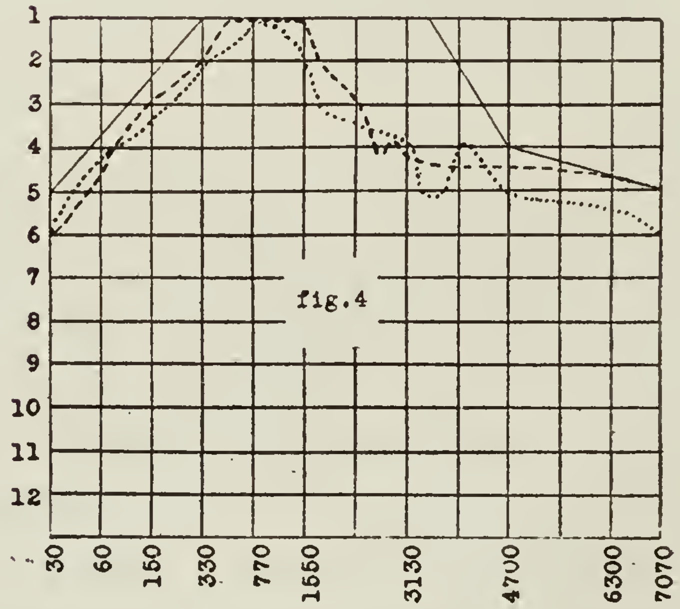
The most significant features of these curves are the tone gaps and islands. A complete gap can be defined as a region in which the loudest tones of the audiometer for certain frequencies are

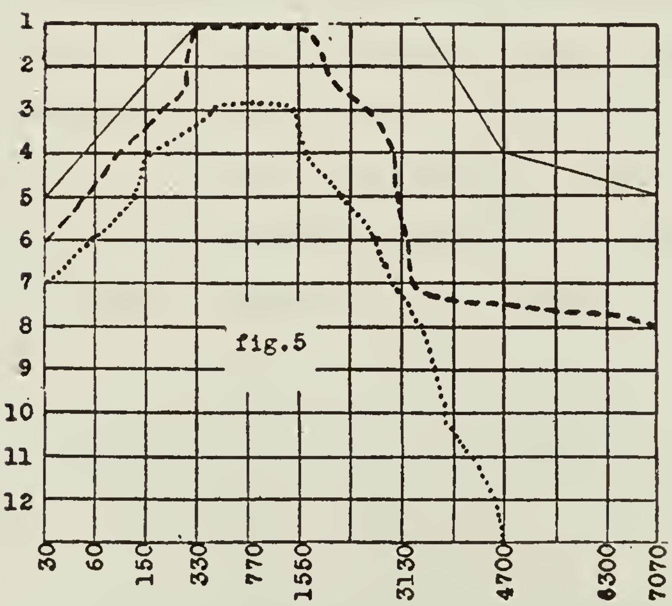
[1] Cases of the type here listed have been reported by Dean, L. W., and Bunch, C. C. The Use of the Pitch Range Audiometer in Otology. *The Laryngoscope*, St. Louis, August. 1919; Dean, L. W., and Bunch. C. C. Results Obtained from One Year's Use of the Audiometer in the Otological Clinic. *Trans. of the Am. Otol. Soc.*, 1920; and Dean, L. W. Studies in Otology Using the Pitch Range Audiometer. *Am. Laryng., Rhinol. and Otol. Soc.*. June 3. 1921.

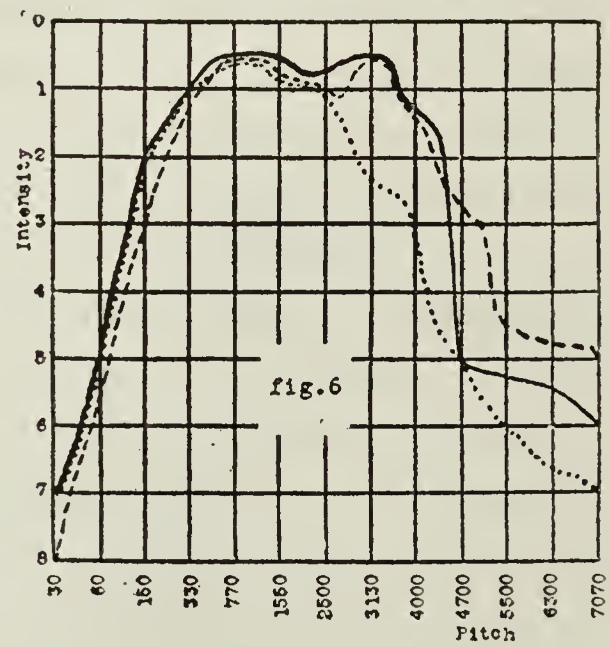












inaudible. Partial gaps are those regions where the tones are heard if they are made sufficiently intense. An island is separated from the rest of the field of hearing by gaps. This is in accordance with the nomenclature of Bezold who defined a gap as a portion of the range in which the tones which he produced were inaudible. It is possible and probable that if sufficient intensities had been available all total gaps would have been reduced to partials. In fact the resonance theory of hearing would apparently necessitate such an explanation.

In the following pages significant curves of ear lesions are shown together with the diagnosis and some of the clinical evidence for the diagnosis.

External ear. For the purpose of determining the exact effect of disturbances in the external auditory canal, a condition of deafness was created in the ears of a patient who had clinically normal hearing by packing the external canal with boric acid and powder. In Fig. 1 the hearing before the ear was packed is represented by a line of dashes and that afterwards by a line of dots. Fig. 2 is for the opposite ear of the same individual. The difference in the height of the two curves represents the success of the attempt to occlude the meatus. The particular feature noticeable is the uniform lowering of the curve throughout the entire range. The general profile of the curve remains practically unaltered.

Figs. 3 and 4 were taken from a soldier who had complained of ear trouble while he was in service in France. At the time of this trouble the army surgeon inserted a piece of medicated cotton in the meatus of the left[2] ear. So far as the patient could tell, this cotton had never been removed. When he entered the hospital he complained of tinnitis in the affected ear and there was considerable tenderness in front of the meatus. Inspection showed that the cotton had remained in the ear since the time of his illness, a period of eighteen months, that the canal wall was reddened and inflamed and that the inflammation extended to the tympanic membrane. The two charts when compared show the effect of the removal of the cotton pellet.

In Fig. 5 is shown an example of the effect of impacted ear wax so common in clinical practice, the line of dashes represents

[2] In each of the curves following unless otherwise stated, the hearing for the right ear is indicated by a line of dashes and that for the left by a line of dots.

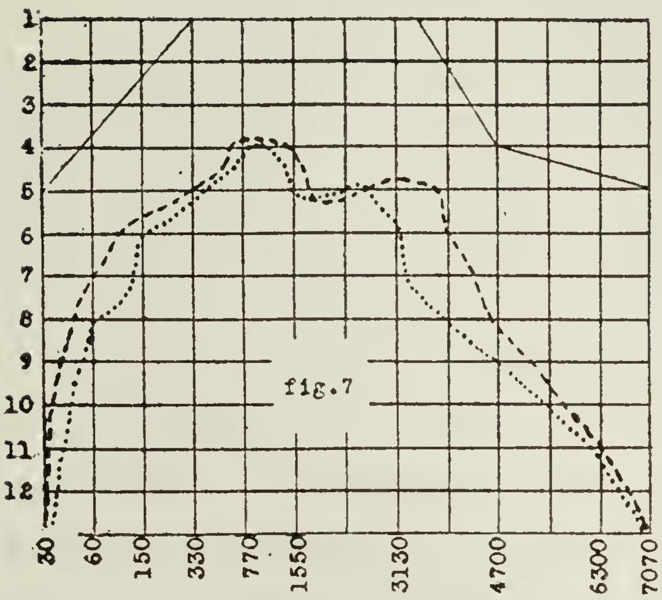
the hearing after the removal of the wax. In place of the uniform lowering of the curve we have a marked lowering for the high tones, a feature which cannot be explained by the packing of the auditory canal. It is evident that other factors enter into the deafness. After the removal of the wax, the observer had a decreased upper limit which was undoubtedly caused by inner ear trouble. This point will be touched upon in a later paragraph.

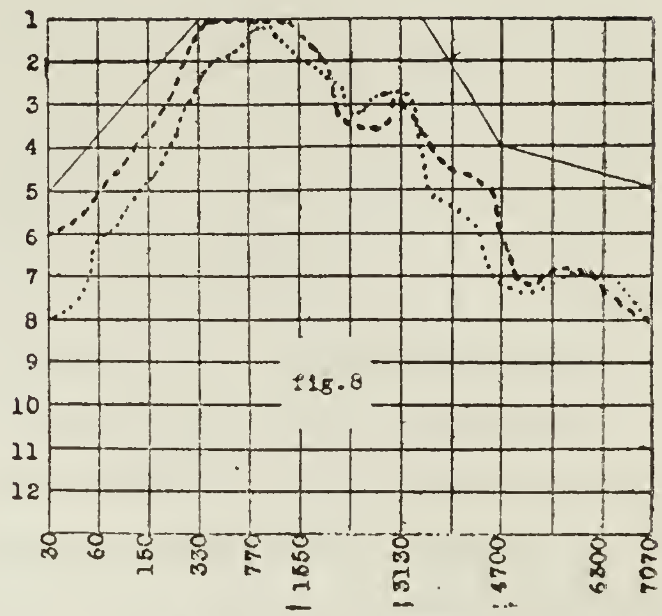
Chart 6 is the result of a test in the case of a slight external otitis in the left ear, a simple infection of the lining of the meatus and perhaps of the outer wall of the tympanic membrane. The hearing for voice was normal. The loss in perception for the higher tones in this ear was too slight to be discovered by the tuning fork test.

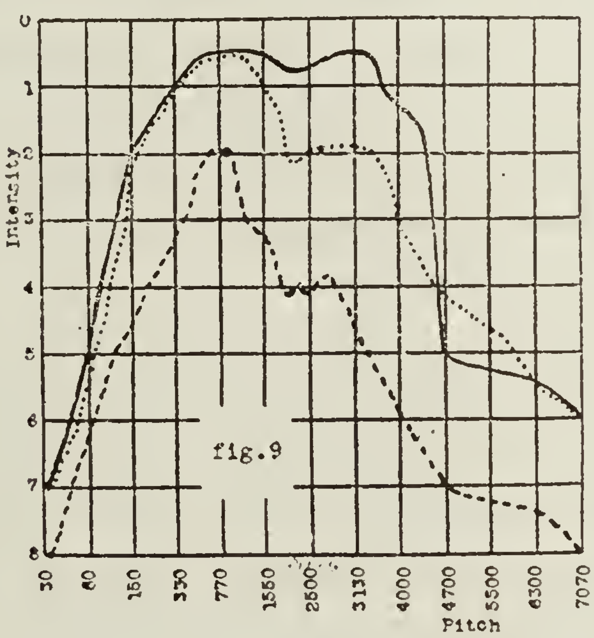
In the case of deafness artificially created, no inflammation was present. The powder remained in the ear but a short time. With the impacted ear there was a slight possibility that there might be inflammation but the tests were made immediately after it was noticed. The wax had undoubtedly been in the ear for some time but was only noticed when the patient went swimming and got some water in the affected ear which caused the canal to become tightly closed. In the case of the cotton pellet and in the external otitis, there was undoubted inflammation to be considered. The results are different in every case, as may be seen from the figures.

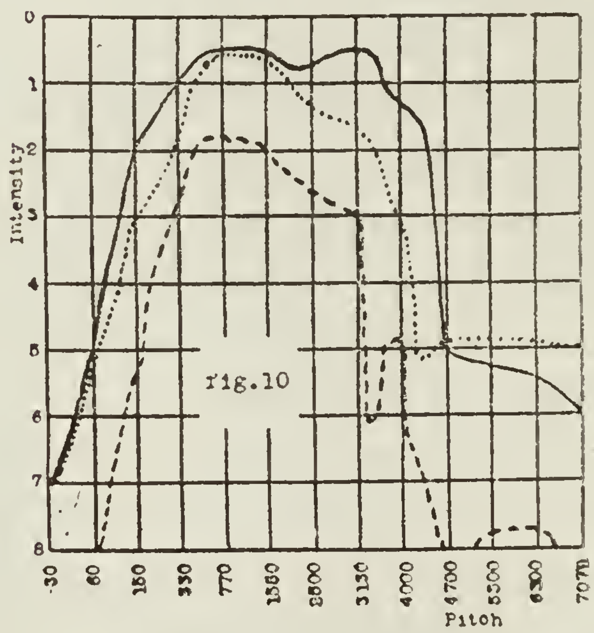
Middle ear deafness. The many varied forms of middle ear deafness and the frequency of such lesions of that region makes this subject of most important clinical significance. If we may believe Emerson (16), no pure middle ear lesion exists, but in the course of this study at least two cases were found which, according to Dr. Dean, presented the features of pure middle ear lesions.

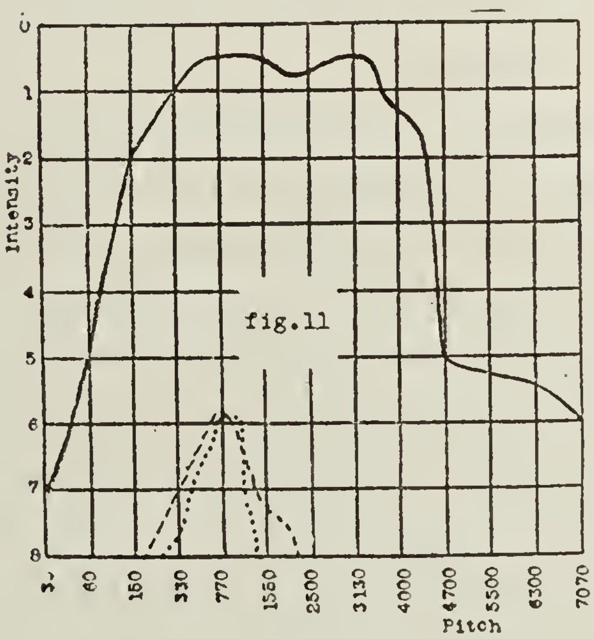
Fig. 7 is for a case of acute tubal catarrh. After this record was made, the eustachian tubes were inflated and the results of a new test are shown in Fig. 8. After the second test was made, the patient, a young man of 19 years of age, remained under observation for ten days. At the end of this period, a third and fourth test showed a condition similar to the one of Fig. 8.











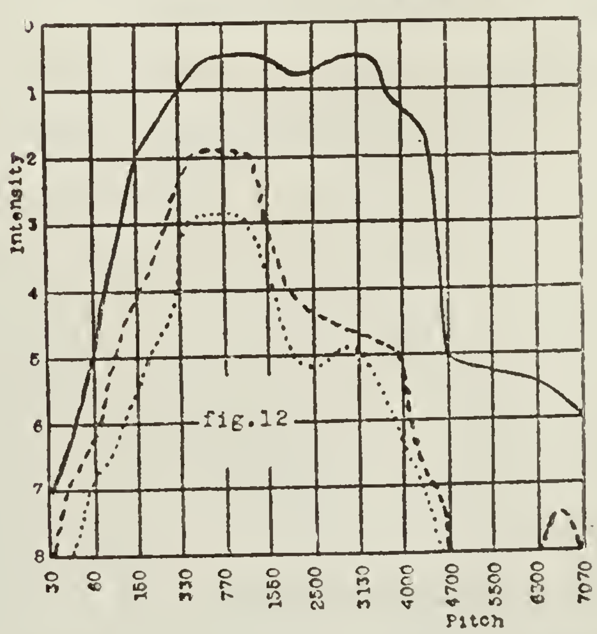


Fig. 9 shows the effect on hearing of an adenoma in the fossa of Rosenmüller in the right side causing a mechanical blocking of the eustachian tube.

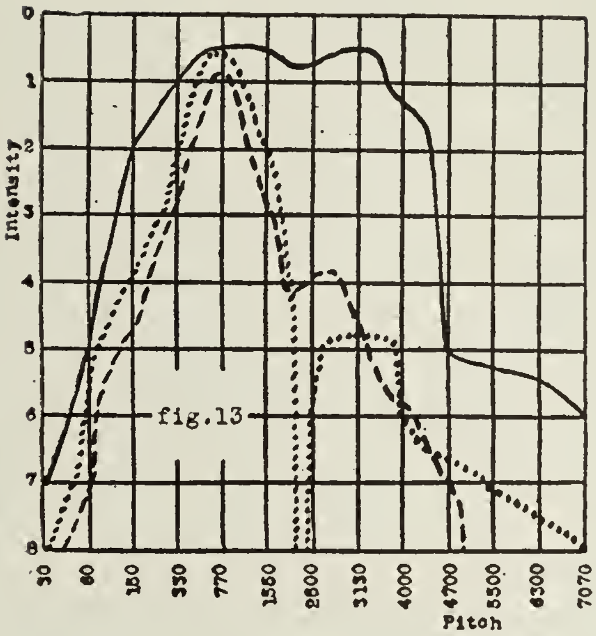
With the other common forms of middle ear deafness such as hyperplastic otitis media, chronic suppurative otitis media, recurrent or acute otorrhoea, etc., the presence of such diagnostic points as the loss of hearing for tones above the range of the audiometer, the loss of perception by bone conduction and the decrease in sensitivity for a limited range of tones, others remaining normal, makes it necessary to consider these evidences of inner ear deafness in making a diagnosis.

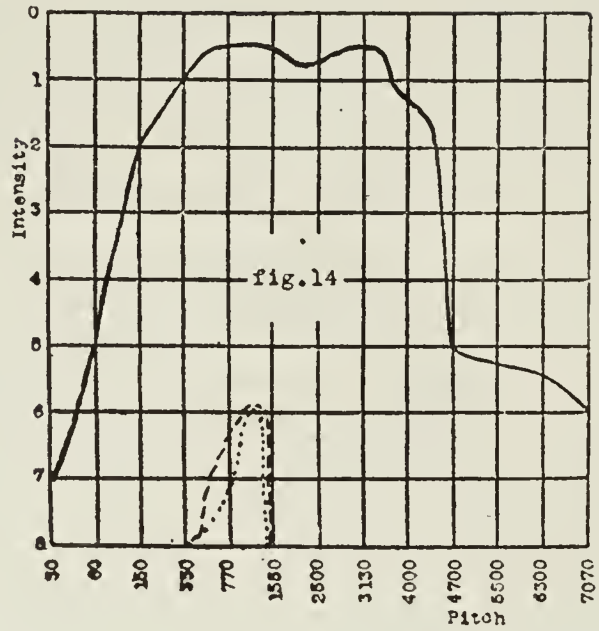
Combined middle and inner ear deafness. A. Chronic otorrhoea with cochlear involvement. Fig. 10 is that of a girl seven years of age. The clinical examination showed the presence of a profuse foul discharge in the right ear which, according to the history of the case, had followed an attack of scarlet fever three years before. The audiometer test distinctly added information to the clinical test in this case. The island shown at 5000 d.v. was between the range of the c^5 fork and that of the monochord so that it was not discovered in the clinical test.

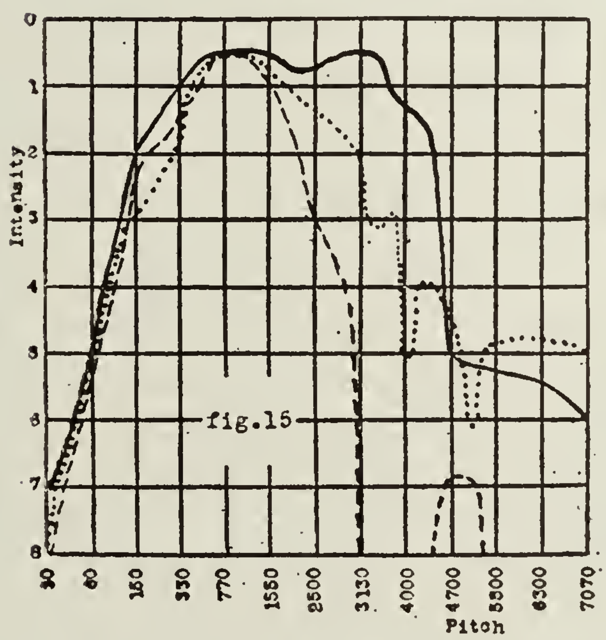
B. Chronic otorrhoea with syphilis. Fig. 11 is that of a woman nineteen years of age. Both ears had been discharging for five or six years but hearing was not greatly diminished. About three weeks before the tests were made, she suffered with dull headaches, the discharge became very profuse and she became almost entirely deaf. At the time of the examination she could hear only the loud voice at one foot.

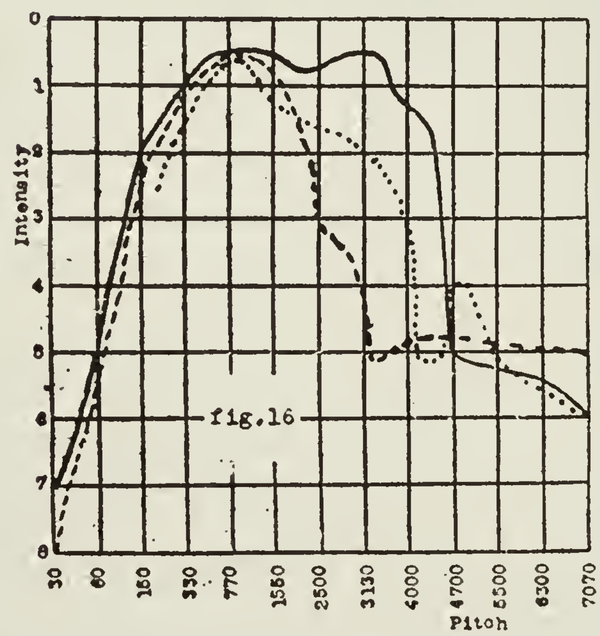
C. Acute suppurative otitis media. Two weeks before the test of Fig. 12 was taken, the patient, a young man of eighteen years of age, had a bilateral infection of both middle ears as a result of getting water into the middle ears while swimming. At the time of the clinical examination the tympanic membrance were inflamed and bulging. Paracentesis was performed but this did not prove sufficient for the left ear. A mastoidectomy was necessary on this side. The right ear appeared to be clearing up without complications. The chart for the right ear shows the presence of an island for tones above 6300 d.v., a possible evidence of inner ear involvement in the ear not operated.

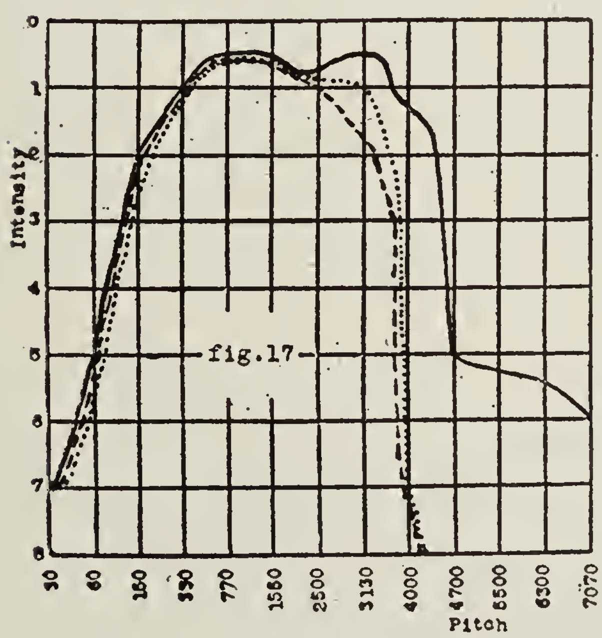
D. Chronic hyperplastic otitis media. Fig. 13 is that of a woman sixty-eight years of age. In the previous clinical examination she was reported as being able to hear the whispered

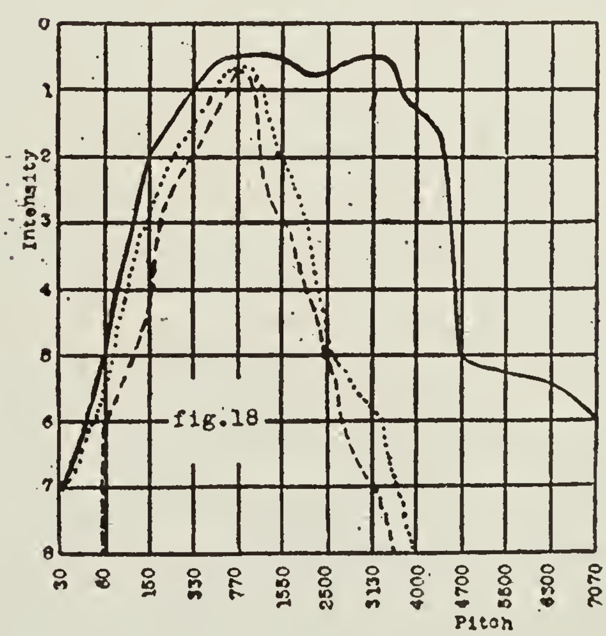












and spoken voice normally. In the first audiometer examination, the gap shown in the curve for the left ear was passed over because of its limited extent and the hurry with which the test was conducted. In the second test, the opposite ear was excluded by means of the noise apparatus and when the test was given properly the gap was found. In the fork tests the c^4 fork was reported audible but when retested, this fork was heard only when struck with a steel hammer and then there appeared to be some doubt as to whether it was the sound of the fork or the impact of the hammer which was heard. This test illustrates the necessity of excluding the opposite ear in tests of this nature, especially when loud tones are used or when there is a great difference in the sensitivity of the two ears.

In hyperplastic otitis media, the condition of the membrane and the eustachian tubes is an important factor in making the diagnosis. With the progress of the disease, the membrane and ossicles seem to lose their function almost entirely. The audiometer curve shows a general lowering throughout the range and the clinical tests show great loss of hearing for the voice. Fig. 14 is illustrative. The patient, a man thirty-three years of age, gives a history of deafness increasing for twelve years. At the time of this examination he could hear a loud voice close to his ears only. The drum membranes were flaccid and covered with trophic areas and the tubal orifices were scarred from previous treatments.

Inner ear deafness. A. Acoustic neuritis. In cases of acoustic neuritis we have loss of perception for the higher tones and decrease in perception by bone condition. Often the perception for the human voice is apparently undisturbed. Where it is possible, the focus of infection or inflammation has been sought and is here recorded.

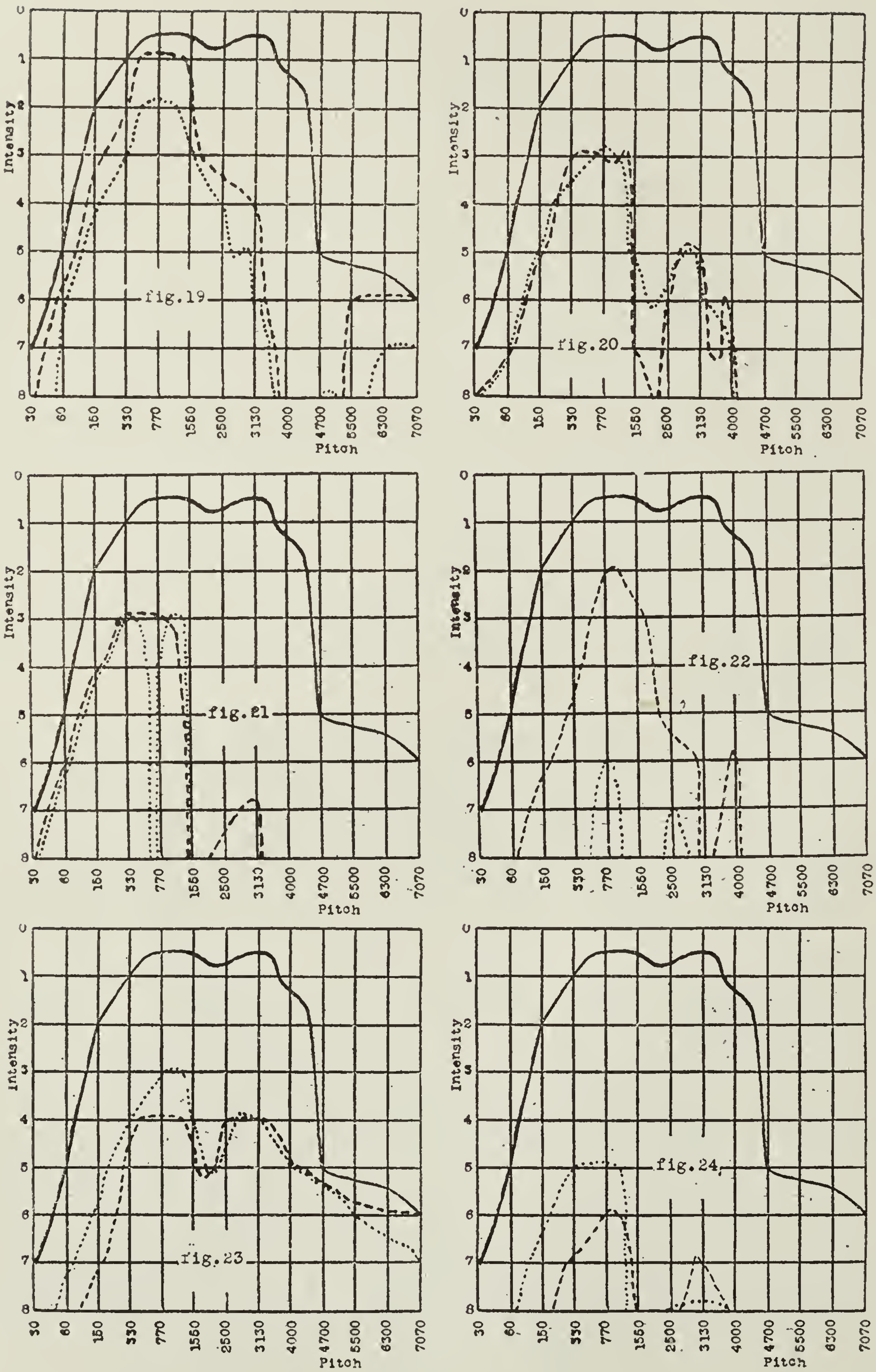
Fig. 15 was taken on January 19, 1921. In this case, the diagnosis given by one of the colleagues of Dr. Dean was considered by him to be questionable. The history of the case seemed to make it possible that the trouble might be other than a nerve infection. However, since the patient had badly diseased tonsils and rather frequent attacks of tonsilitis, he was advised to have the tonsils removed and followed the advice at once. On June 23 another test was given with the results shown in Fig. 16. There is apparently a return of perception for the tones in the upper portion of the range. The patient notices that his hearing in ordinary life is much improved. The diagnosis of acoustic neuritis with the focus of infection in the badly diseased tonsils is apparently justified by the recovery of his hearing after the removal of the tonsils.

Fig. 17 is that of one of the clinical assistants. Previous to this test, this surgeon had not been aware of any deafness and was, in fact, conducting the routine hearing tests of the clinic. There is a decided loss in hearing for the upper portion of the scale covered by the audiometer. The perception for the c^5 fork is very much decreased. However, the upper limit as determined by the Galton whistle, the monochord and the Koenig cylinders is practically normal. His perception by bone conduction is lessened. In this case, since there is no indication of the presence of a focus of infection, the neuritis has been ascribed to the excessive use of tobacco which is held to be the cause of similar toxic conditions.

Fig. 18 is that of a syphilitic patient, male, forty-seven years of age. In the early stages of syphilitic deafness there has often been shown to be a definite improvement as a result of systemic treatment. In the case here shown, one of cerebro-spinal syphilis, the usual anti-syphilitic treatment resulted in no measurable improvement in audition. As in so many cases where the curve has this general contour, this patient thought that his hearing was good except when his head "felt stopped up" with a bad cold.

B. Neuro-labyrinthitis. Fig. 19 is that of a man, twenty-one years of age who was in the eye service of the clinic. The routine test revealed a loss of hearing for the c^5 fork. The audiometer test gave the islands and gaps indicative of inner ear deafness. In the presence of no focus of infection and because of the general appearance of the patient, he was given a tuberculin test. This was followed by the marked local reactions typical of tubercular patients. With tuberculin treatment extending over three weeks, there was a marked improvement in the hearing. The treatment and reaction verified the diagnosis of toxic labyrinthitis.

Fig. 20 is from the examination of a yong man of seventeen.



The history given was almost negative. Deafness had extended almost from the time his parents could talk to him. The Wasserman test was negative and there was no apparent focus of infection to cause the deafness but in his examination his parents reported that he had had a severe case of mumps when he was three years old, and in the absence of other evidence or etiological factors, it was decided that the deafness resulted from the mumps.

The eitological factor in Fig. 21 is pellagra. The record is from a man sixty-five years of age. The records for the voice tests in this case were right, whisper 6 in. spoken 2 ft., left, whisper 6 in. spoken 6 ft. This and the following curve shows a rather peculiar effect of a nutritional disease.

In Fig. 22 leukemia is the etiological factor. The patient is a man sixty years of age.

C. Otosclerosis. The curve shown in Fig. 23 is that of a lady twenty-seven years of age. In the test made three years before the record shown here the case was diagnosed as otosclerosis, the type being that in which the head of the stapes becomes fixed. The patient gives a history of deafness on the maternal side of the three preceding generations. At the time of the first test, the hearing was almost normal, the only disturbing factor being distressing tinnitis. With the Gelle test, the patient gave the positive response.

A second type of otosclerosis is illustrated in Fig. 24, that of a woman fifty-two years of age. The negative Rinne, increased bone conduction, paracousis of Willisii and history of gradually increasing deafness preceded by distressing tinnitis is rather typical of this type of deafness. At the time of the test, voice was heard at one foot.

Conclusion

The curves given above are selected because they are typical. The description accompanying each chart is intended only to add to the information given by the curve in order that the points of diagnosis may be more evident to those skilled in drawing such conclusions. Throughout the study, however, several outstanding features of the work have been very evident.

1. Clinical evidence for diagnosis which has been passed over in a thorough clinical test of two hours duration has been brought to light in a test of fifteen minutes with the audiometer.

2. Incipient lesions impossible of determination with the tuning fork tests have been determined with the audiometer because complete quantitative determinations are possible.

3. Because of the possibility of exact acuity determinations, the audiometer has been materially helpful in differentiating between diseases of the inner and the middle ear.

4. Tone gaps and islands are much more common in clinical practice than is ordinarily thought to be the case. In this study, tone gaps and islands, more or less inceptive, have been found in 43 per cent of the cases tested.[3]

5. The audiometer in the hands of the clinical assistants is much more reliable in its results than a set of forks. In tests where there has been an apparent discrepancy between the results found in the fork tests and those of the audiometer, checking has always proven the results of the fork tests to be in error. The results of the audiometer test are more comprehensive, less time consuming and more accurate than a routine test with octave forks.

[3] These cases are not, however, entirely unselected. Often it was inadvisable to test a case when it was presented at the clinic. Children too young to respond properly to the instructions were not tested. Those ill enough to demand immediate care were not tested. On the other hand, Dr. Dean kindly submitted many of his most interesting private cases for tests.

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MEASUREMENT OF AUDITORY ACUITY WITH THE IOWA PITCH RANGE AUDIOMETER

by

By Benjamin Franklin Zuehl, Ph.D.

Description of apparatus; procedure and technique for testing; norms of auditory acuity; conclusions; bibliography.

The purpose of this study is to establish norms of acuity in hearing for individuals who are generally considered normal in hearing ability, and to discover the general tendencies in the distribution of acuity as well as types of deviation from the norm. Such norms are valuable particularly for the purpose of comparison in diagnosing pathological cases and for determining fitness for certain vocational and professional activities (18).

This study is a sequel to several years' work in the field of audition in the laboratories of the State University of Iowa which has resulted in the construction of the Iowa Pitch Range Audiometer; this apparatus is a result of the efforts and cooperation of several departments, principally Otology, Physics and Electrical Engineering with that of Psychology (9, p. 3).

The pioneer work, both in developing the instrument and devising a method of procedure, was done by Dr. C. C. Bunch, acting as research assistant in the psycho-physics of otology. In the University Hospital this method was used in the otological clinic and has demonstrated its superiority to other diagnostic devices so convincingly that examination with the audiometer has been substituted for tuning fork tests (4).

Description of Apparatus

The apparatus used in this investigation is the fifth model of the Iowa Pitch Range Audiometer and represents a further development of the instrument used by Dr. C. C. Bunch (3, pp. 66 *ff.*), the principal differences being special frictionless bearings for the generator shaft, a more practical gradation of intensity steps, and the installation of the control board and listeners' equipment in the silence room. The motor and generators were inclosed in a heavy felt-lined wooden box which was suspended by ropes from an overhead support in an adjacent room.

The details of the present model are shown in Fig. 1, and consist essentially in the following: two sound-generators as shown in Fig. 1, A and C; a D. C. motor Fig. 1, B; an electric tachometer Fig. 1, D. These are mounted on a cast-iron base Fig.

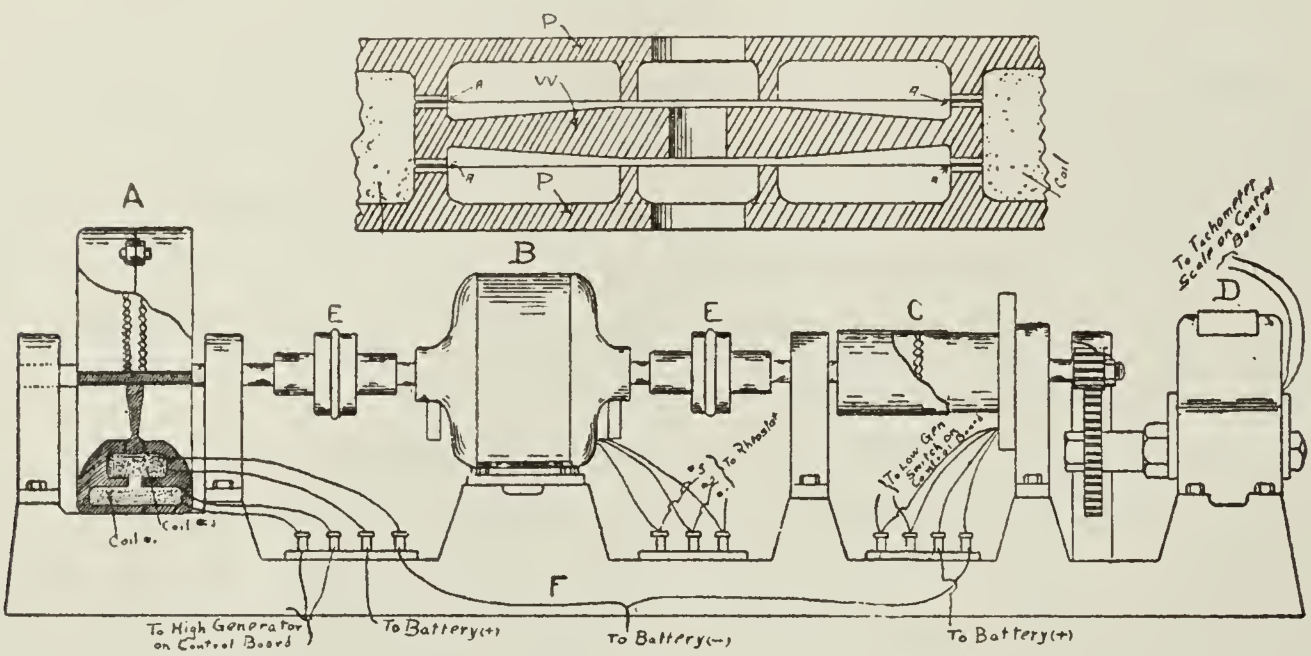

FIG. 1. Tone generators, motor and tachometer mounted on iron base. A = large generator; C = small generator; B = motor; D = tachometer; F = cast iron base; EE = insulated shaft couplings. Details of large generator shown in section in the upper figure; PP = stationary plates; W = rotating disc; AAAA = space between cogs.

1, F. Binding posts are fastened on the base for the necessary connections; twelve dry-cell batteries were used to magetize the generator coils. The balance of the apparatus was installed in the observation room and consists of the following parts: a control board shown in Fig. 2, a signal key and telephone receiver (not shown). The control board is made of asbestos board,[1] rëenforced with an angle-iron frame, set on edge at an angle convenient for operation and observation by the experi-

[1] The asbestos control board absorbs moisture from the atmosphere in damp weather causing a short circuiting. It should therefore be replaced by a rubber or stone slab.

menter, it is equipped with motor switch, signal light switch, rheostat and control lever, resistance control, double generator switch, telephone cut-out and a tachometer scale, all shown in Fig. 2. The tachometer is calibrated so that the pitch of the

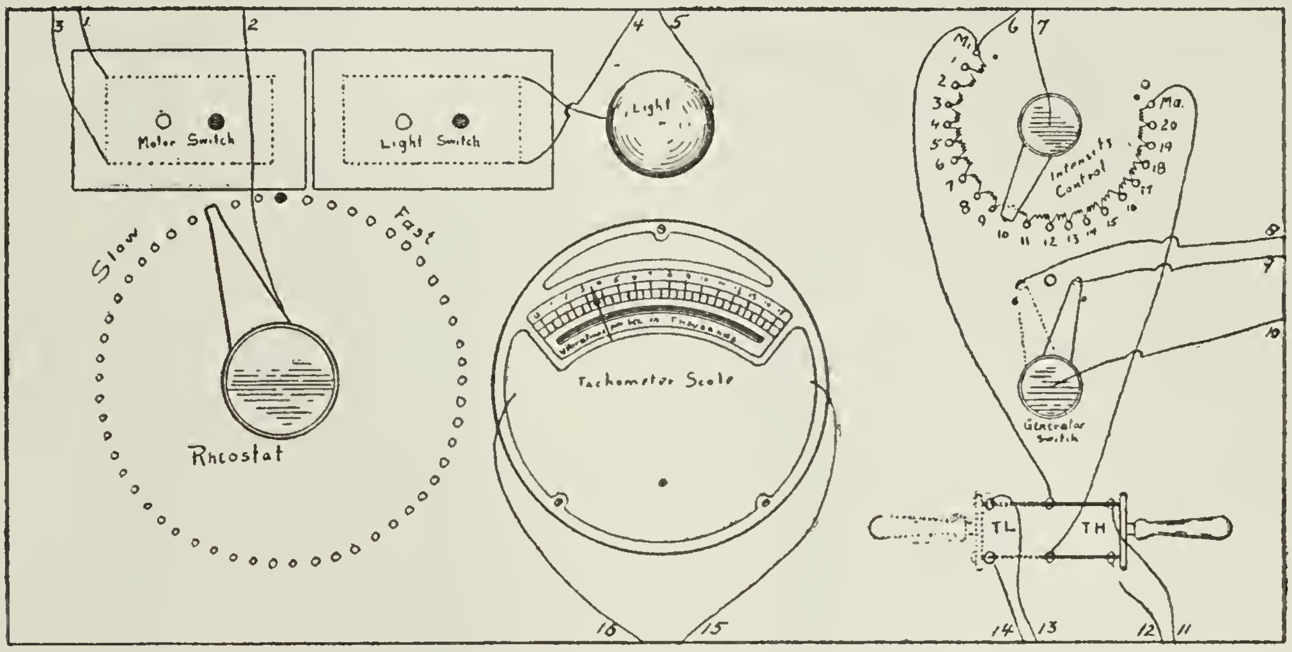

FIG. 2. Control board. 1, 2 and 3 = connections with motor; 4, 5 = signal key connections; 6, 7 = wires to telephone receiver; 8, 9 and 10 = battery connections; 11, 12 = to high generator; 13, 14 = to low generator; 15, 16 = to tachometer.

tone can be read directly, the readings being in thousands per second when using the large generator, and in hundreds per second when using the small generator, since the number of radial cogs on the small generator is one-tenth as many as those on the large generator.

The double generator switch makes it possible to connect either the large or small generator with the batteries, or to disconnect them entirely; the latter should be done when the apparatus is not in use, in order to save the batteries.

The telephone cut-out, Fig. 2, T. L. and T. H. not only serves the purpose of connecting the telephone with the desired generator, but also enables the experimenter to interrupt the circuit for the purpose of control trials.

The device for controlling the resistance, (and hence the intensity of the tone as heard in the telephone) consists of a series of twenty-one non-inductive resistances installed in series with the generators, (Fig. 2). The contact which represents minimal intensity, (indicated by "Mi." Fig. 2) is not absolute zero resistance, since a number of observers can hear the tone at the most favorable pitches.

TABLE I. *Intensity scale in terms of resistance*

Designation of intensity steps	Resistances (in ohms)		Per cent of increase
	Increments	Total	
Minimal	.0	Minimum	——
1.	.000025	.000025+	?
2.	.0000375	.0000627	250
3.	.000094	.0001567	250
4.	.000235	.0003911	250
5.	.000586	.000977	250
6.	.001465	.00244	250
7.	.00366	.0061	250
8.	.00915	.0152	250
9.	.0228	.038	250
10.	.057	.097	250
11.	.1425	.2375	250
12.	.35625	.59375	250
13.	.890625	1.4843	250
14.	2.226	3.71078	250
15.	5.565	9.275	250
16.	13.9125	23.187	250
17.	34.78	57.9675	250
18.	86.95	144.918	250
19.	217.37	362.288	250
20.	543.432	905.72	250
Maximal	1358.58	2264.3	250

The scale of resistances is shown in Table I. Each of the contacts in the intensity control establishes its circuit through the telephone terminals as the switch is shifted from one to the other. The potential drop across the terminals of the telephone can therefore be varied at will by the experimenter and the loudness of the tone can be registered in terms of the resistances.

The two tone generators are constructed on the same principle: a metal disc with radial cogs or teeth, is rotated before a similarly constructed stationary disc. The large generator is equipped with 150 cogs and the small one with 15. A primary and secondary coil is constructed around each set of discs, so that the cogs pass each other in the magnetic fields of the coils. Fig. 1 shows the coils for the large generator in cross section. The large generator has radial cogs on two faces of the rotating disc, and hence has two stationary plates, one on either side; the small generator has radial cogs on only one face, and hence one stationary plate. In both cases the distance between the plates is .007 inch and is kept uniform; a magnetic arc is formed across this air gap when the crests of the cogs on one wheel pass those of the other. This magnetic impulse actuates the telephone diaphragm at a rate determined by the number of cogs passing each other per second, and the latter is in turn controlled by the speed of the motor; hence the pitch of the tone varies with the speed of the motor. The small generator is necessary in order to get accurate readings for the tones ranging approximately from 30 dv. to 700.

In setting up the apparatus it is necessary to have twelve connecting wires leading from the motor, generators and tachometer to the control board. The three wires leading from the motor to the rheostat, and the two, from the tachometer to the scale on the control board may be bunched together in one cable; the other wires should be kept separate from the five in the first group to prevent induction. The wires from the control board to the telephone should also be kept separated from those leading to the signal key, since the latter carries a D. C. which may also cause induction if brought near the telephone wires.

Accessory tones from the motor and bearings are heard along with the stimulus tone proper when running at very high speed; these become disturbing at approximately 7,000 dv. and more and more disturbing with higher frequencies.[2]

[2] Several methods were used to eliminate this disturbance, or to modify it so that reliable records could be obtained for frequencies above the 7,000 d.v. pitch. A high resistance and condenser was installed in series with the generators and the telephone in order to find an adjustment which would dampen the accessory tones without affecting the stimulus tone; the result was not satisfactory, since both the stimulus and accessory tones were damped alike.

The second effort was directed to the modification of the diaphragm; following nodal series of sand figures artificial nodes were attempted, by the use of beeswax, which would have the effect of producing anti-nodes for the accessory tones. The results of this method were not conclusive, but indicated that not much advantage was derived for the high frequencies. The damping effect was noticeable also for low and middle range stimulus tones.

Having failed in the attempt to eliminate these accessory noises for high tones, we modified the procedure in such a way that the observer can hear the accessory tones alone at first. This is accomplished by increasing the speed of the motor to a frequency where the stimulus tone is inaudible. The motor is then slowed down until the stimulus tone becomes clearly audible and can be distinguished from the much lower accessory tone.

Procedure and technique for testing

The accuracy of the hearing tests depends largely upon the preliminary attunement of the observer; the readiness with which the situation is grasped and the adaptability of the individual to the conditions of the test must furnish the first important cue for the experimenter. In fact, the behavior of the observer must be studied carefully and rapidly during the preliminaries so that the method of procedure may be modified in a way favorable to the individuality of the observer.

The procedure which was finally adopted may be summarized briefly under the following directions:

Aim to determine the contour of the area of hearing, making a record on a norm blank like Plates I. to IV.

Use a given intensity as a constant and vary the pitch until the limit for that intensity is found. Vary the pitch at a rate most favorable for precise location of the threshold.

Proceed from "sound heard" to "sound not heard," Tu, (threshold under); but verify and control frequently by using the reverse order, To, (threshold over), without recording. If the Tu is too uncertain above 1,200, use the To for that region.

Determine the contour in three sections: 4,000 to 500 dv.; 750 to 30 dv.; and 14,500 to 4,000 dv.

Begin with the better ear, if known, or with the right ear, and change ears for each of the three above sections.

Verify gaps and islands or minor irregularities in contour in fine detail.

Avoid fatigue by alert action on the part of both experimenter and observer, and if many repetitions are necessary, allow intervals of rest for that particular pitch. Normally a thorough test for both ears should be made in 25 minutes.

When it is found that one ear is very inferior to the other, it is advisable to close the better ear with the finger, or use a buzzer so that the sounds will not be heard with the superior ear, but both of these devices must be used with extreme caution.

The two ears may be charted on the same blank. In making the chart, it is convenient for the experimenter to make pencil check marks to indicate the readings, using different signs for right and left ear. It is well to fill in the curve as the test proceeds. The final chart may then be made by inking the records for the right ear in black and for the left in red.

Observers

In this study two-hundred and seventy-five observers were tested.[3] The observers were divided into three groups according to their respective ages. Those in group I. were pupils in the University Elementary and Junior High School, 25 boys and 25 girls, representing ages from 6 to 15 years. Group II. constitutes the largest age group tested, 100 males and 100 females. These cases may be regarded as a random selection among second year students in the University, of a superior type to the extent that college students in general are superior to an unselected group. The advanced age group is the smallest in point of numbers; these observers were members of the University faculty, other educators, and a few citizens of Iowa City who were not engaged in any particular profession. An effort was made to have chance selection operate at a maximum for all observers and artificial selection was avoided as far as possible, except as stated in the above note on pathological cases.

[3] A number of charts were rejected when it was discovered that the observers were taking treatments from a physician and the principal motive for having the test made was to ascertain their relative hearing ability under these circumstances.

TABLE II. *Age Distribution*

Group I		*Group II*				*Group III*	
Age	Number	Age	Number	Age	Number	Age	Number
6	1	17	1	29	1	42	1
7	2	18	15	30	3	45	2
8	2	19	38	32	1	47	2
9	1	20	37	33	3	48	1
10	1	21	38	34	1	49	1
11	4	22	22	35	2	50	1
12	10	23	14	36	2	52	1
13	4	24	6	37	1	54	4
14	10	25	2	38	1	55	2
15	15	26	3	39	1	56	1
	—	27	3	41	1	60	2
		28	4		—	63	2
			—			65	3
						70	1
						73	1
							—
Totals	50	Totals			200	Totals	25
Av. Age	13	Av. Age			22	Av. Age	56
Median Age	13	Median Age			21	Median Age	57

Norms of auditory acuity

The norms which are shown by Figures 3-6, were compiled according to the following method: the charts were first sorted into three age groups (Table II.) and the tabulations for right and left ears were made separately for the purpose of comparison; the frequency and intensity values were compiled on a scattergram and frequency readings were tabulated for each vertical line from 30 to 14,500 dv. inclusive. This made a total of thirty-eight frequency values for each ear; since the intensity variations are by steps, twenty-two in all, these were taken as the proper units for tabulation. These values were then added for each frequency and intensity, the medians computed, also a percentile distribution on the basis of the highest 10%, the lowest 10%, the middle 40% and the 20% between the middle 40% and the highest and lowest 10% respectively. The boundaries of the zones representing this distribution as composites for each group, (Figures 3, 4 and 5) are shown as follows: the superior 10% is outlined on the upper side with dots, except where it extends beyond the area of the chart proper, and its lower limit is a line of dashes and small circles; the latter is the

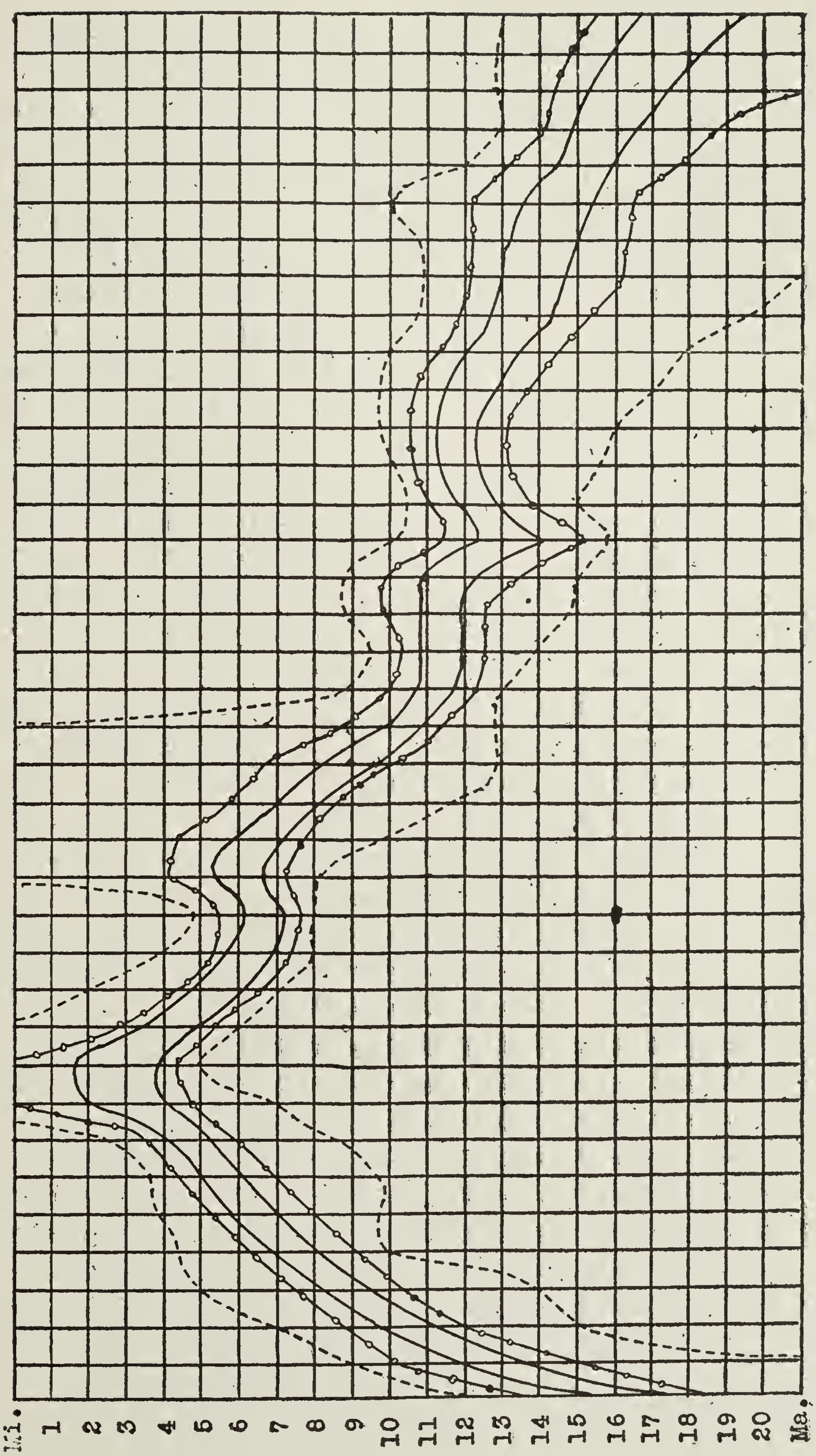

FIG. 3. Composite curve, Group I. Ages 6 to 15 years. Intensity steps indicated by figures in vertical column to the left; Mi. = minimal intensity; Ma. = maximal intensity. The numbers below chart indicate pitch.

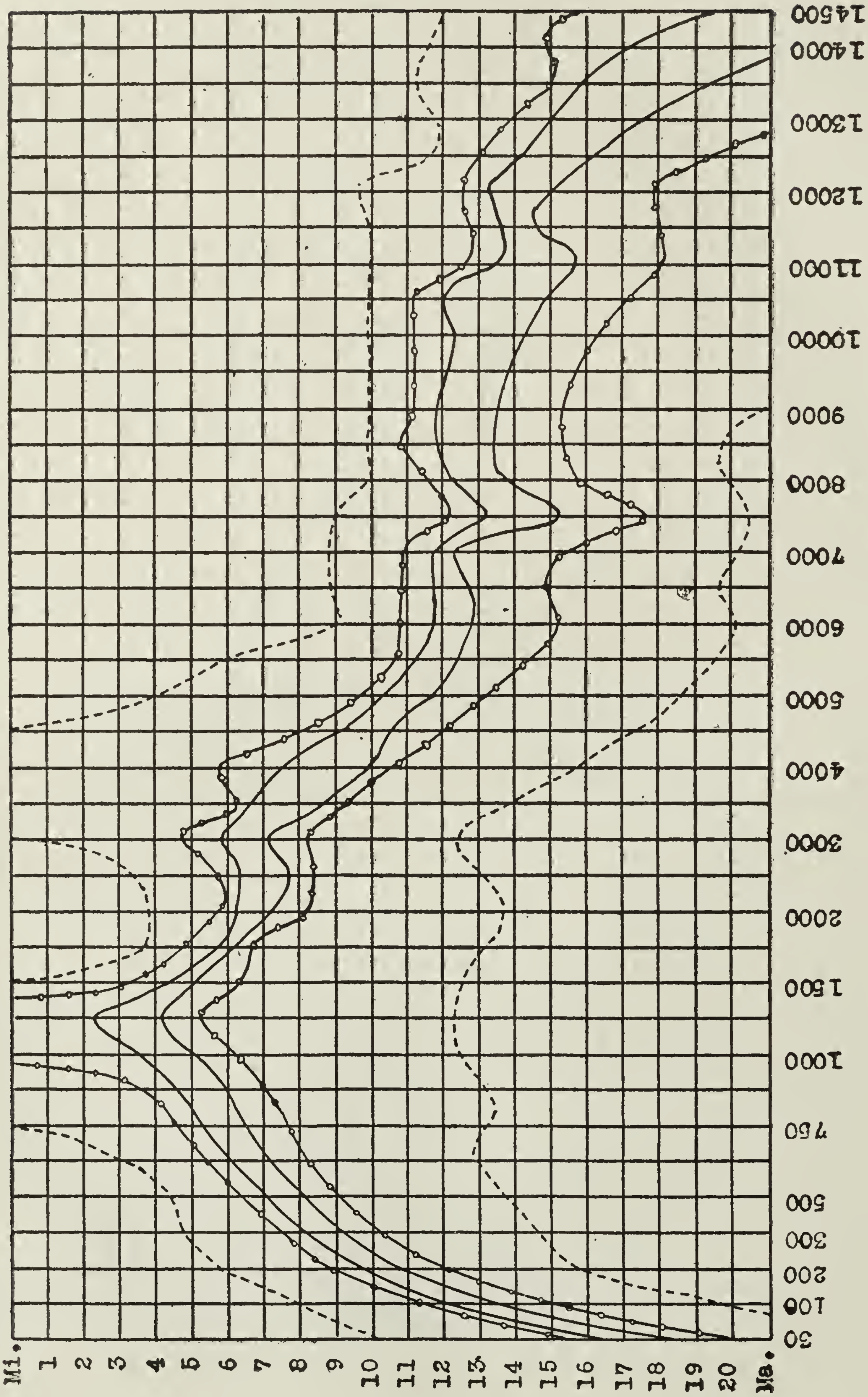

FIG. 4. Composite curve, Group II. Ages 17 to 41 years.

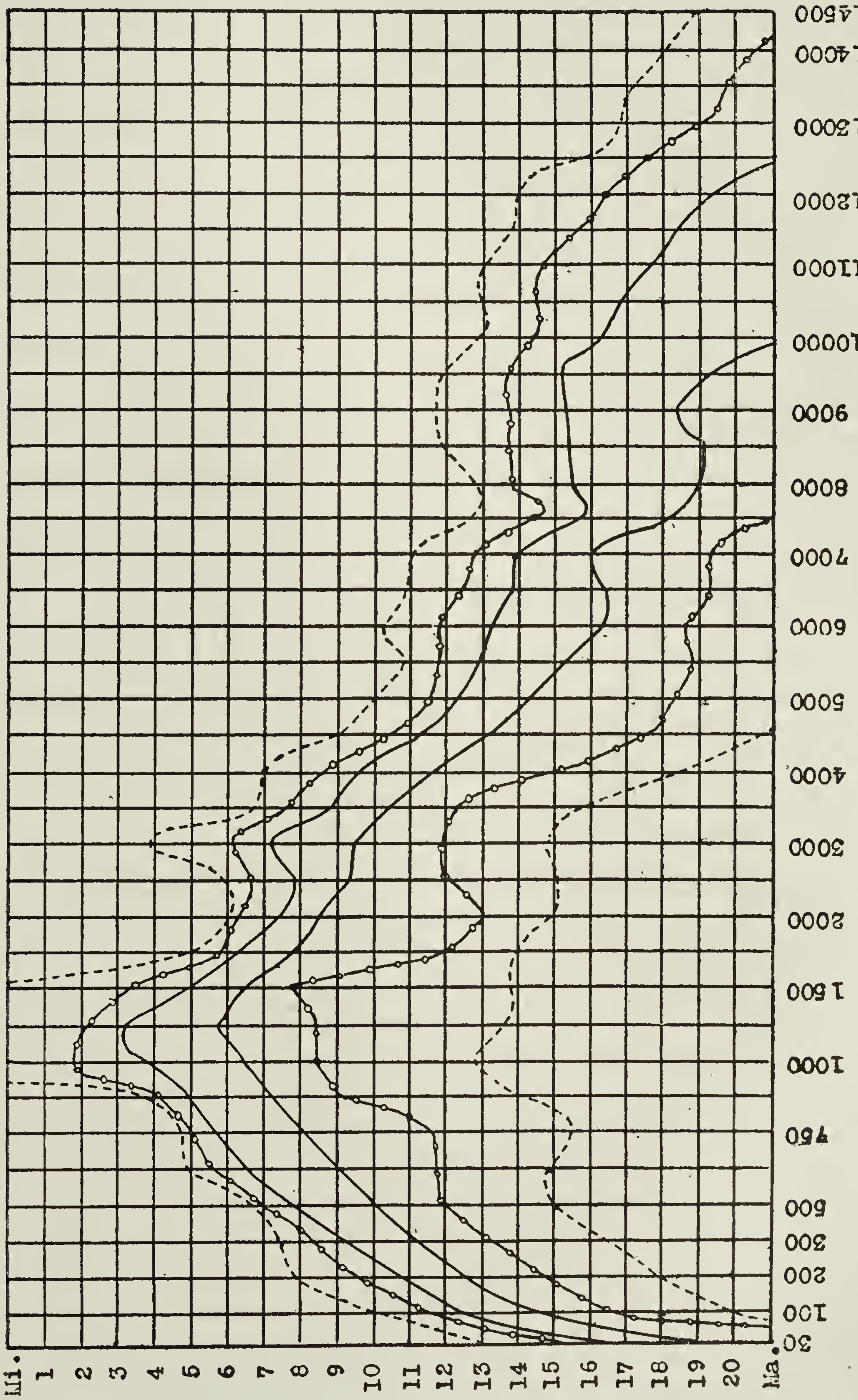

Fig. 5. Composite curve, Group III. Ages 42 to 73 years. Notation same as in Fig. 3.

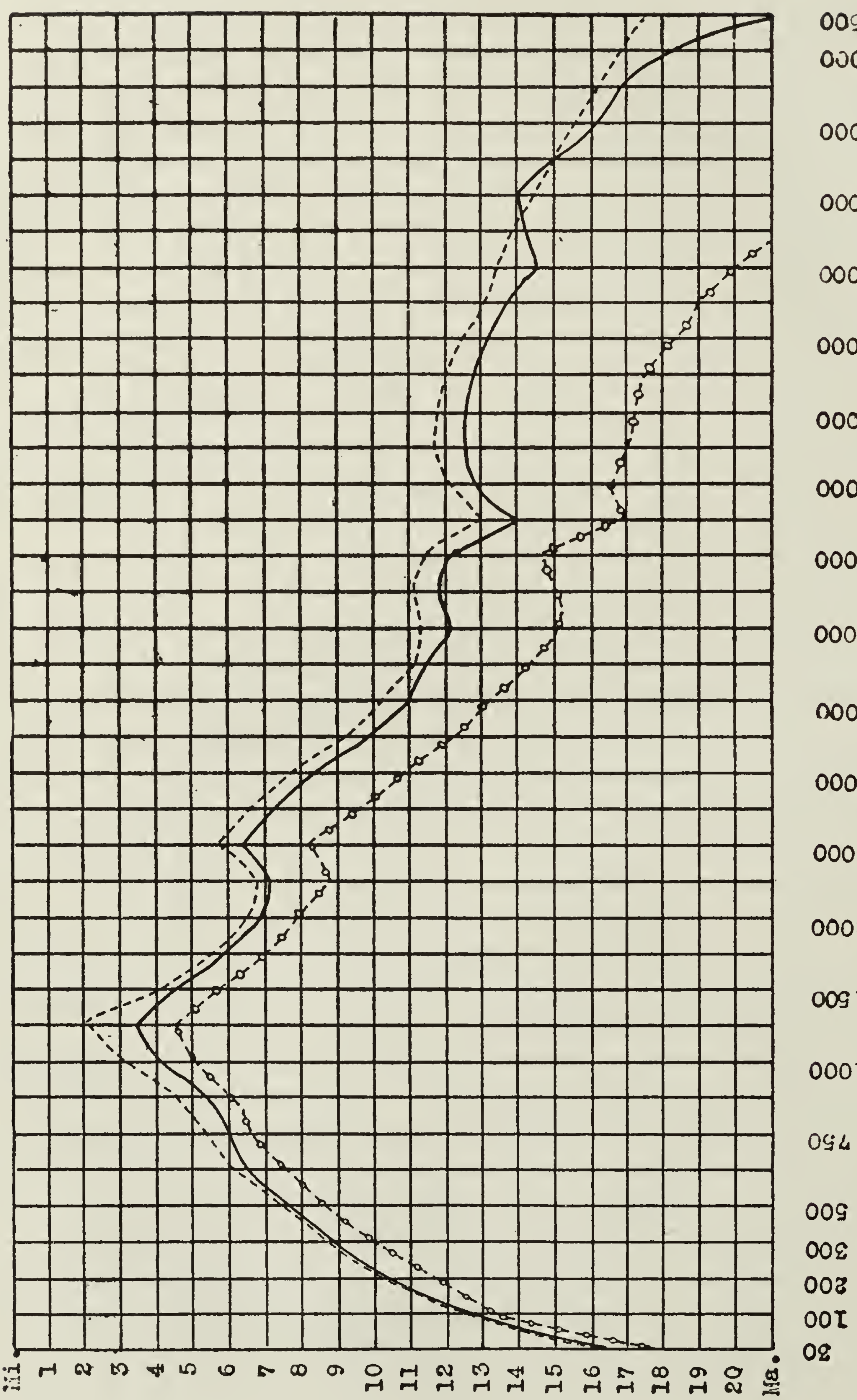

Fig. 6. Medians or groups I, II and III. Dotted line = median for Group I; solid line = median for Group II; dotted line with small circles = median for Group III.

upper limit of the next lower 20% zone, the lower limit of which is indicated by a solid line; the middle 40% is between the two solid lines; the next lower 20% is just below the lower solid line and its lower limit is the line of dashes and circles; below the latter lies the lowest 10%, bounded by the dotted line at its lower limit.

It is to be noted that these are composite curves and the efficiency of an observer may be high at one part of the curve and low at another. If, *e. g.*, he ranks in the highest 10% area at one frequency it is no warrant that he is also superior in the balance of the range. For comparison, the median for each of the three age groups is shown in Fig. 6.

The audiometer tests continuous pitches, but not continuous intensities, and the steps of the latter were chosen arbitarily; however, after trying both larger and smaller steps a 250% increment was accepted as suitable. In fact a moderately accurate hearing test can be obtained by using only every alternate step, which may be done to save time and avoid fatigue, but it is far more reliable to use every step, which was done in this study.

Conclusions

1. The norms for the respective age groups may be used as a reliable and serviceable basis for estimates of relative auditory acuity of individuals.

2. The results show that diminution in ability to hear high tones (above 4,000 dv.) occurs with advanced age.

3. There is less variation in acuity for hearing tones which correspond to the range of the human voice than for any other frequencies.

4. The greatest variation appears in the range of very high tones; above 7,500 dv.

5. The central values of the composite hearing curves deviate uniformly from a straight line; these deviations are not tone gaps or tone islands, but are due to the apparatus and normal factors in the auditory mechanism.

6. Deviations from the norms are due primarily to individual

differences in auditory sensory end organs including the acoustical parts, and secondarily to non-auricular factors operating in the observer, *e.g.*, motor, intellectual, emotional, etc. (14).

7. A significant inferiority in hearing ability may be present in one or both ears without the individual being aware of it.

8. An inferiority of two intensity steps at points within the frequencies corresponding to the speech range is to be regarded as significant.

9. Gaps are more prevalent in the range of high frequencies, but are more significant in daily life when they occur in the low frequencies. This does not apply to diagnostic significance.

10. The general efficiency of one or both ears may be stated in terms of arbitrary units representing directly or indirectly the area included within the limits of the curve and the base line representing maximal intensity.

11. Accurate relative measures cannot be bunched as stated in conclusion No. 10, but can only be stated in terms of two specific values, *i.e.* pitch and intensity.

12. Gaps and tonal islands can be definitely described in terms of pitch and intensity.

13. Children manifest a superior ability to hear high tones, the most significant superiority begins at the 6,000 dv. frequency.

14. Events in health history have a higher correlation with variations in hearing ability than the latter have with chronological age.

15. No significant difference was found between male and female observers of the same age group (Cf. 11).

16. No significant difference was shown between right and left ear abilities, except in the advanced age group; the superiority of the right over the left ear in the third group is significant if it is representative, however the number of observers was rather limited to be conclusive.

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A STROBOSCOPIC DEVICE FOR MEASURING REVOLUTION RATES

By Benjamin Franklin Zuehl, Ph.D.

An inexpensive device for measuring rotation rates can be made by mounting two paper discs on rotating axes. If the rate of one is known, the rate of the other can be determined by finding the ratio between the two speeds stroboscopically. One disc may be put in place of a record in a good phonograph. The rate of revolution can be set accurately enough for general purposes by counting the revolutions during several minutes. This then furnishes the part of the apparatus necessary for producing a known speed.

In case of a practical application, the other disc was mounted on the top of the vertical axis of the tone generator of the Iowa Pitch Range Audiometer as shown by Seashore.[1]

For convenience in description the disc which is placed on the phonograph will be designated as No. 1, and the stroboscopic disc whose rate is to be determined as No. 2. The diameter of No. 1 is 24 cm. In it are six concentric circles of holes made with a paper punch 4 mm. in diameter. There are 12 dots in the innermost circle; in the next larger circle 14, and so on, increasing by two's; the outside circle then has 22 dots. The radial spacing is 14 mm. for each successive circle. This spacing of the circles is favorable for making the readings without confusion.

Disc No. 2 has a diameter of 18 cm. It may be larger or smaller as the rotating shaft and apparatus will permit. Six concentric circles are laid off on this disc, the smallest with a radius of 78 mm., the next 93 mm., and so on, lengthening the radii of the respective circles by 15 mm. The number of apertures in these circles, beginning with the innermost and toward

[1] "Psychology of Musical Talent," pp. 90, 91, Silver, Burdett & Co., Boston.

the outer, are, 1, 4, 8, 12, and 24 respectively. The size and shape of these apertures is important. From the inner circle outward the apertures measure 9 mm. by 17 mm. the long dimension being at right angles to the radius; 9 mm. by 14 mm.; 9 mm. by 9 mm.; 9 mm. by 3 mm.; and 9 mm. by 1 mm. respectively.

As will be seen from the accompanying table, the inside circles of disc No. 2 are used for high rates of speed and the outside for slower speeds and the differences in the size of the apertures give an exposure suited for forming the retinal image, on the principle that when the aperture moves slowly a narrow slit will give a similar interval for retinal reaction as a wide opening will when it is rotated more rapidly.

It is advantageous for making rapid readings to have different colors as a background for the various circles of holes on the stroboscopic disc corresponding to the respective frequencies. Over each disc a scale is mounted designating the circle by number or letter.

Disc No. 1 must be set below and to one side of disc No. 2 so that it is easy to look down through disc No. 2 upon No. 1. The two discs may rotate in any plane, the only limitation being that they shall permit a free line of vision through one to the other; they may also rotate in the same or opposite directions.

When both discs are set in motion, at certain speeds a row of dots on No. 1 will be seen standing still or nearly still; this takes place when one set of apertures of disc No. 2 synchronizes with the dots in that row on disc No. 1 or come in multiples of it. To get the rates, divide the number of dots in the circle on disc No. 1 by the number of apertures in the circle of disc No. 2 through which the observation is made; the quotient will give the number of revolutions made by disc No. 2 while disc No. 1 makes one revolution. If no row stands still but two adjacent rows move slowly in opposite directions, read by the one that moves the more slowly. The correct reading lies between these two rows and is represented by the inverse of the ratio of the two speeds. Thus, if one row moves at the rate of one space in 8 seconds and the other in the opposite direction at the rate of one space in 2 seconds, then the reading is one fourth of the number of units from the former line and three fourths from the latter, whatever the two speeds may be.

The speed of disc No. 1 should be fixed at that frequency at which it can be kept most uniform, since it is used as a chronometer and all the readings will be accurate in proportion to the degree of accuracy with which this disc rotates.

TABLE I. *Scale for making frequency readings: Number of revolutions per second of Disc No. 2 for each revolution of Disc No. 1.*

	1	4	8	12	24
12	12	3	1.5	1	.5
	24	*6*	*3*	*2*	*1*
14	14	3.5	1.75	1.16+	.58+
	28	*7*	*3.5*	*2.32+*	*1.16+*
16	16	4	2	1.3+	.65+
	32	*8*	*4*	*2.6+*	*1.30+*
18	18	4.5	2.25	1.5	.75
	36	*9*	*5.5*	*3*	*1.5*
20	20	5	2.5	1.8	.9
	40	*10*	*5*	*3.6*	*1.8*
22	22	5.5	2.75	1.83+	.96+
	44	*11*	*5.5*	*3.66+*	*1.92+*

Numerals at the top give number of apertures in the respective circles of Disc No. 2. Numerals at the left give number of holes in the respective circles of disc No. 1. Double speeds in italics.

In the present apparatus one revolution of disc No. 2 denotes 150 vibrations. The scale shown in Table I is therefore capable of giving readings of vibrations from 37.5 vd. to 3300 vd. by direct reading, or 75 vd. to 6600 vd. if read by the first multiple.

The chief advantages of this speed measuring device are that (1) it measures rates of revolution accurately, (2) it is adaptable to a wide range of frequency rates and measures every speed within its range, (3) it can be used when the discs rotate in other than horizontal planes, and (4) it is inexpensive, hence convenient for small laboratories.

Among its limitations are the facts that (1) it requires some training on the part of the person making the readings, (2) it gives a ready measurement of speeds at only certain points within its range, the speeds between these must be calculated by an indirect method, and (3) the two discs must be in a certain relative position with respect to each other in order to be seen.

However this device will likely find many uses in laboratories which are not equipped with the more expensive speed measuring devices.

VISUAL TRAINING OF THE PITCH OF THE VOICE

By

CARL J. KNOCK, PH.D.

The main series of experiments; the supplementary series of experiments; relation of pitch hearing to accuracy in singing; the effect of difference in quality of the standard tone; relative accuracy of the different intervals; similarity of the errors of the different tones; judging the difference in pitch of one's own voice and the pitch of the fork.

This study is one in a series on the problems of pitch of the voice in singing conducted in the psychological laboratory of the University of Iowa. The object was threefold: (1) to ascertain the effect of accurate checking of errors on accuracy in pitch singing; (2) to determine in some measure the elements responsible for inaccuracies in pitch singing; and (3) to isolate some factors in improvement with practice.

The measurements were all made with the tonoscope, (5) a standard 256 dv. fork and a König resonator.

There were two series of experiments. The one we shall designate as the *Main Series of Experiments* and the other as the *Supplementary or Intensive Series of Experiments.*

The Main Series of Experiments

Observers. The observers in this series, four men and eight women, were all in the University either as students or as instructors. None of them had had any work in psychology beyond a year of elementary psychology. Six of them were at that time taking that course. Although three of the observers were taking voice work, they were all amateur singers. The men were very much of the same even temperament and had good control of themselves. The women, on the other hand, differed very much in disposition and temperament, some of them being rather nervous and erratic. The three women who were taking voice work came purposely to act as observers because of their difficulties in controlling their voices in singing in pitch.

Method of procedure. The experiment in the main series consisted in the singing of four tones: the standard, the major third, the fifth, and the octave. The standard, or key-note tone, was taken from the 256 dv. fork. The fork was energized by striking it on a suspended piece of padded lead and was immediately presented in front of the resonator for about two seconds. The experimenter endeavored to keep timbre, intensity, and duration of the tones as uniform as possible. The observer began to sing the standard as soon as he had the tone from the resonator clearly in mind and, after a moment's pause (about one second), sang the interval.

The men sang the standard tone as 128 dv. The third, the fifth, and the octave should therefore be 160 dv., 192 dv., and 256 dv., respectively. The women sang the standard as 256 dv.; their third, fifth, and octave were therefore respectively 320 dv., 384 dv., and 512 dv. If the standard tone was sung sharp or flat, the third and the fifth were calculated from that and not from the the true standard, because the interval seemed to be measured from the standard as sung. Three measures were used in the evaluation of the data, viz., average error, constant error, and mean variation.

Three series.—The main series of experiments was divided into three parts: namely, Series I, or first unaided series; Series II, or practice series; and Series III, or final unaided series. The object of Series I was to ascertain how accurately the observers sang and whether they would of their own accord discover the errors in their singing and correct them. Series II, as indicated, was the practice series, the object of which was to develop finer tonal concepts and better voice control. The object of Series III was to determine how effective the training in Series II had been, and whether or not gain made under controlled conditions could be carried over into actual practice in ordinary singing.

Series I and III were identical in method of procedure. Five tests were given in each of these series. Each test consisted in singing the following series of tones twenty times: standard and third; standard and fifth; standard and octave, and then back in reverse order. Hence, the standard was sung sixty times and each interval twenty times during a test.

Since the object of Series I was to determine how accurately the observers sang before training, and that of Series III how accurately after training, no information was given the observers in regard to their errors in these series until the end of each series. In series I they were asked to sing in their natural way. In Series III they were told to keep in mind the information given in Series II in regard to their errors and tendencies in singing and to endeavor to make such changes in pitch as they thought desirable.

The tests in Series II were conducted in slightly different manner from those of the other two series. Instead of singing the tones in the order given in the other series, they were sung in the order: standard, standard and third, standard and fifth, standard and octave, each ten times in succession. This order of procedure was followed because information in regard to the accuracy of pitch was given after the singing of each tone, and, in order to profit by the corrections, immediate repetition of the tone was thought to be most effective. Information was given in terms of vibrations; *i.e.*, if the observer sang the tone out of pitch he was immediately informed as to just how much sharp or flat he sang. Having in mind the tone just sung, and the knowledge of his error, he endeavored to make proper corrections in the next trial. Thus it was possible to note from tone to tone the nature of the differences in sensations produced by the slight variations in pitch, and thereby develop a more accurate concept of the pitch of the tone. In order to get the correct tone fixed in the mind, the intervals were not sung until the standard was first sung with reasonable accuracy after prompting. The standard tones sung before the interval-tones were not taken into consideration as measures of accuracy in singing the standard. Before taking any records of an interval a short time was spent in practicing that interval and getting the accurate pitch of that tone fixed in the mind.

After singing each tone, and before the experimenter informed the observer of his error in pitch, the observer gave his own judgment as to the accuracy of the tone sung and this was recorded. The results of these experiments are summarized in Tables I and II, and Figures 1-15.

Table I. *General Summary of Records*

	I. First Unaided Series				II. Practice Series				III. Final Unaided Series			
	1st	3rd	5th	8th	1st	3rd	5th	8th	1st	3rd	5th	8th
					Observer *A*							
Av.E.	3.6	4.1	4.7	2.9	1.2	1.8	1.1	2.0	2.8	4.4	4.1	2.4
M. V.	3.3	3.8	3.9	2.6	1.4	1.5	.9	1.7	2.8	2.8	4.0	2.7
C. E.	2.4	3.3	3.2	—1.5	—0.5	1.0	—0.6	—0.9	2.0	3.2	3.1	0.3
					Observer *B*							
Av.E.	2.0	3.9	4.2	5.1	1.5	1.4	2.9	1.9	2.1	4.0	4.6	4.8
M. V.	1.4	2.4	2.4	2.7	1.5	1.3	2.5	1.9	1.4	2.5	2.6	2.9
C. E.	1.6	2.7	1.7	4.6	0.8	—0.6	—1.6	0.0	1.7	3.2	2.8	4.6
					Observer *C*							
Av.E.	7.3	5.9	7.6	8.5	3.2	2.3	3.4	3.6	3.3	3.5	6.4	5.0
M. V.	3.6	4.2	4.9	5.0	3.0	2.2	3.4	3.7	2.4	3.4	6.0	4.6
C. E.	6.6	3.8	5.5	6.7	1.7	1.0	—0.7	1.1	—2.0	—0.6	0.4	—1.8
					Observer *D*							
Av.E.	4.3	7.1	7.8	10.9	1.8	.9	1.7	3.0	2.3	3.5	2.5	2.8
M. V.	2.3	3.3	4.6	4.8	1.9	1.1	1.7	2.4	1.6	2.2	2.3	2.6
C. E.	4.0	7.0	7.5	10.6	0.4	—0.1	—0.4	2.2	2.0	2.7	0.2	0.7
					Observer *E*							
Av.E.	8.2	4.5	6.4	2.6	1.8	1.8	2.0	4.1	3.4	4.0	4.2	3.2
M. V.	2.1	2.1	2.8	2.3	1.8	1.6	2.0	3.0	3.1	3.3	3.9	3.3
C. E.	5.5	3.7	4.2	1.3	—0.6	1.3	—0.4	—0.6	0.9	2.2	0.7	—0.7
					Observer *F*							
Av.E.	1.8	2.7	2.6	6.2	2.0	2.2	1.6	3.7	1.2	2.2	2.4	2.5
M. V.	1.4	1.8	2.0	3.3	1.4	2.0	1.3	3.1	1.0	2.1	2.3	2.6
C. E.	0.4	—2.3	—2.0	—5.8	1.7	—1.2	—0.6	—1.7	0.4	0.5	—0.4	—0.3
					Observer *G*							
Av.E.	2.6	8.4	7.4		1.4	2.6	3.0		1.4	4.6	5.6	
M. V.	1.6	2.1	3.7		1.2	2.8	3.0		1.4	3.1	5.2	
C. E.	2.1	8.3	6.5		0.9	0.8	0.2		0.6	1.5	—0.5	
					Observer *H*							
Av.E.	3.9	5.3	6.4	5.9	1.7	2.6	2.3	5.2	1.8	4.3	3.6	3.9
M. V.	2.4	4.9	4.9	4.0	1.5	2.6	2.3	4.2	1.5	3.2	3.8	3.2
C. E.	3.3	—1.4	—1.3	—0.4	0.8	0.0	1.1	0.9	0.8	0.3	0.9	3.0
					Observer *I*							
Av.E.	2.2	1.5	1.8	1.8	.5	.6	.8	1.4	1.0	1.6	2.4	2.5
M. V.	.7	.8	1.1	1.4	.5	.6	.6	1.1	.9	1.1	1.8	1.7
C. E.	—0.2	—1.2	—1.0	1.5	0.3	—0.2	0.3	1.3	0.3	0.2	0.6	1.3
					Observer *J*							
Av.E.	1.1	1.9	3.9	1.0	.4	1.0	2.0	.9	1.2	2.3	3.0	.7
M. V.	1.0	1.5	1.7	1.0	.4	.8	1.9	.8	1.0	1.9	2.5	.7
C. E.	—0.3	—0.7	—3.4	0.6	0.0	0.6	—1.2	—0.1	0.9	1.6	0.9	0.4
					Observer *K*							
Av.E.	2.2	2.4	1.9	3.4	.4	1.1	.5	1.1	1.4	1.8	1.6	2.5
M. V.	1.0	1.1	1.2	1.4	.3	.7	.4	1.0	.8	.9	.9	1.3
C. E.	—2.1	2.3	1.5	3.4	0.5	1.0	0.2	0.9	—0.1	1.4	0.8	2.3
					Observer *L*							
Av.E.	2.2	3.8	4.7	3.2	.6	.7	1.1	1.3	.8	1.6	2.5	1.7
M. V.	1.0	1.1	2.0	1.5	.6	.7	.9	1.2	.6	1.2	1.5	1.3
C. E.	2.2	3.8	4.7	3.2	—0.1	0.4	—0.6	0.5	0.2	0.2	—1.9	—0.1

Observers *A* to *H* are women; *I* to *L* are men. For each observer the first line gives the *average error* (Av.E.), the second the *mean variation* (M.V.), and the third the *constant error* (C.E.)

Table II. *Summary showing gain in* II *and net gain in* III

MEN

	Series I Ave. E.	Series II Ave. E.	Series II Gain	Series III Ave. E.	Series III Net Gain
Standard	1.9 dv.	.5 dv.	77%	1.1 dv.	42%
Third	2.4	.9	62%	1.8	25%
Fifth	3.1	1.1	64%	2.4	21%
Octave	2.3	1.2	47%	1.9	22%

WOMEN

	Series I Ave. E.	Series II Ave. E.	Series II Gain	Series III Ave. E.	Series III Net Gain
Standard	4.2	1.8	57%	2.3	45%
Third	5.2	1.9	63%	3.8	27%
Fifth	5.9	2.3	61%	4.2	30%
Octave	6.0	3.4	43%	3.5	44%

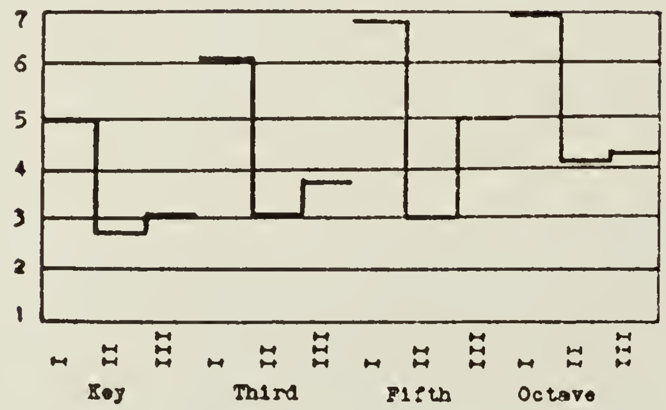

FIG. 1. Achievement in training the voice by the aid of the eye (from Table 2). Numerals at botton denote Series I, II, and III respectively; numbers at left average error in the terms of vibrations. The amount by which III is lower than I for each interval indicates the amount of net gain through the training of the eye in Series II.

The Supplementary Series of Experiments

The object of this series was to study the effect of intensive training with accurate checking of errors in pitch. The method of procedure was different from that of the previous series. The observers in this series were *J* who participated in the main series of experiments and *Kn,* the writer, who had gained acquaintance with the situation by having served as experimenter throughout. Observer *J* has a good baritone voice and plays the violin, but has not had much musical training. His pitch discrimination threshold is about .4 dv. In the foregoing series he sang the standard and the octave the most accurately of all the observers, but he could not correct the flatting of third and fifth. On account of this fact he undertook the more intensive practice.

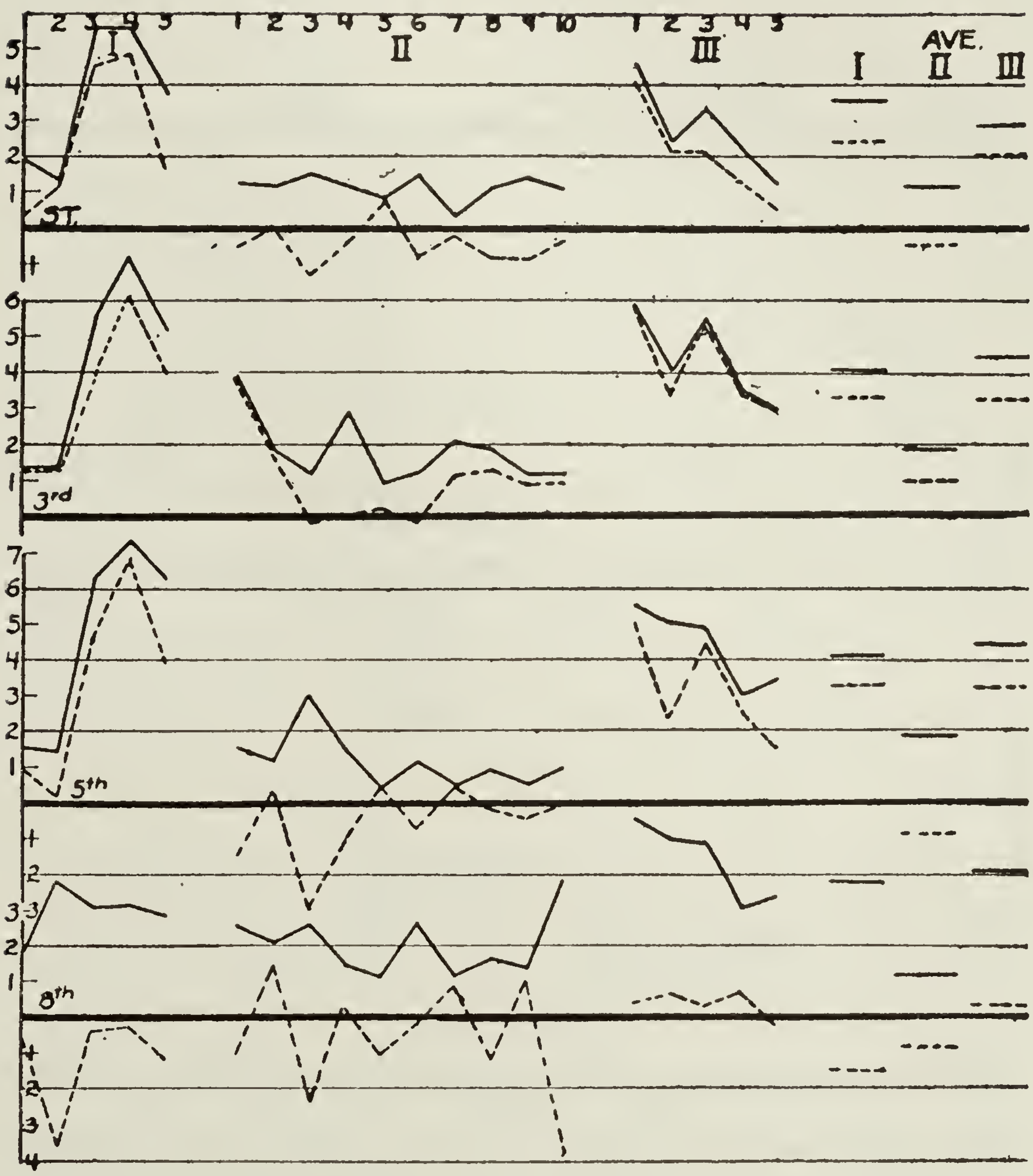

FIG. 2. Observer A, Soprano. Pitch discrimination (P.D.), 1.7 dv.

The solid line denotes average error (A.E.); the broken line, constant error (C.E.). The figures at the left denote number of vibrations of deviation from the standard (the heavy base line). The figures at the top denote the successive days for each series. "Ave." gives the average A. E. and C. E. for each of the three series. This notation is the same in succeeding figures.

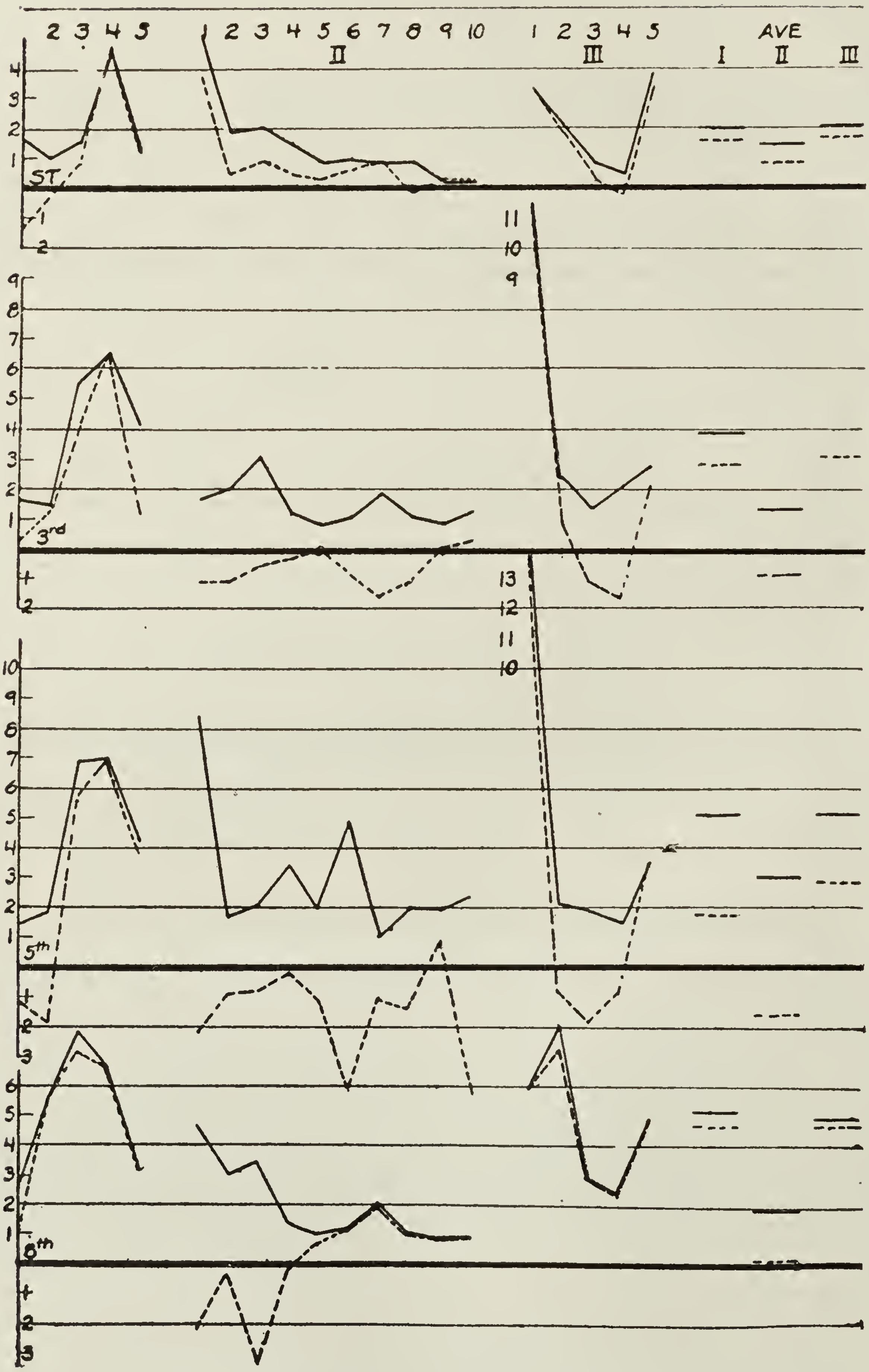

FIG. 3. Observer B, Soprano; P. D., .8 dv.

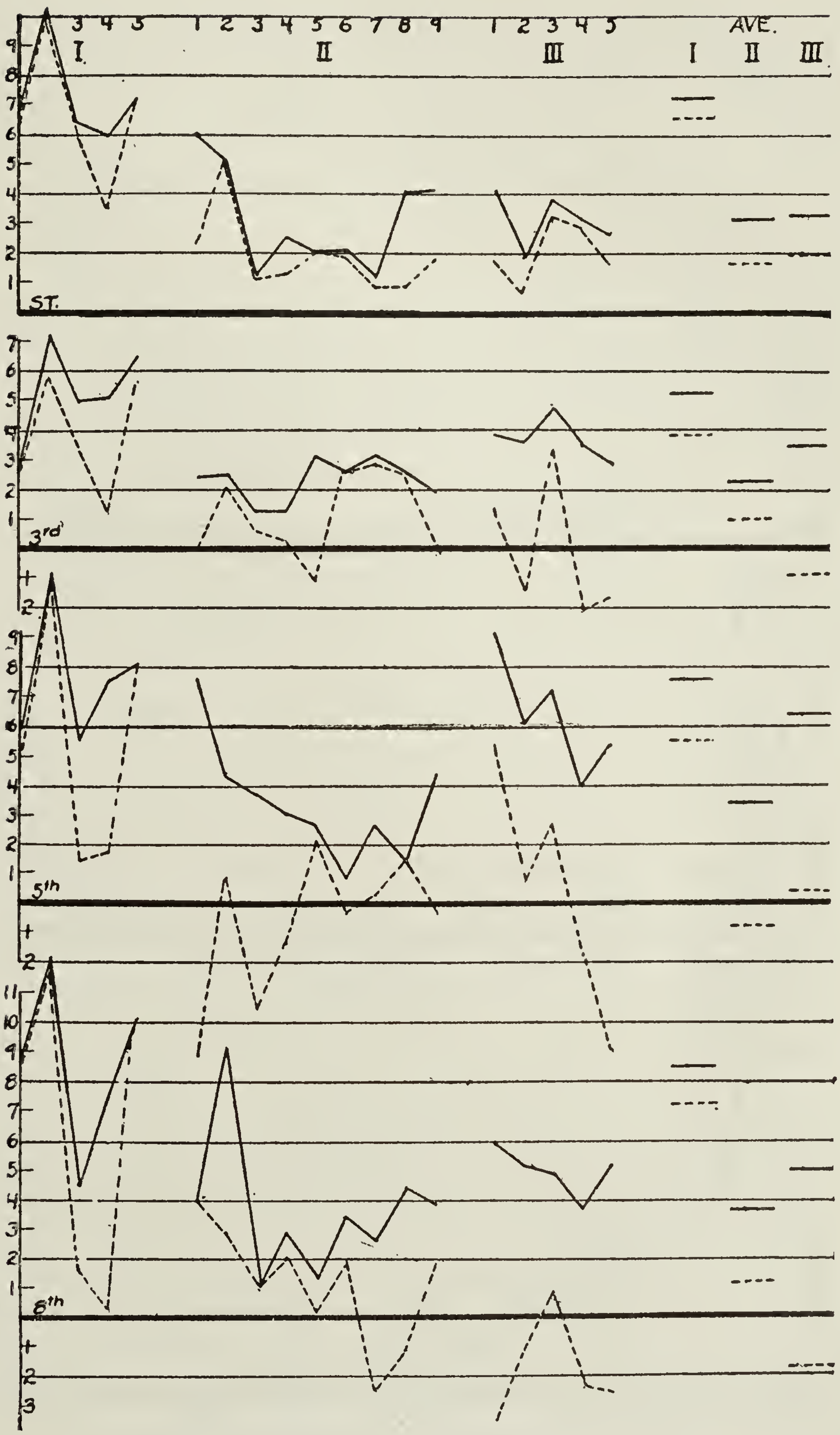

FIG. 4. Observer C, Soprano; P. D., 1 dv.

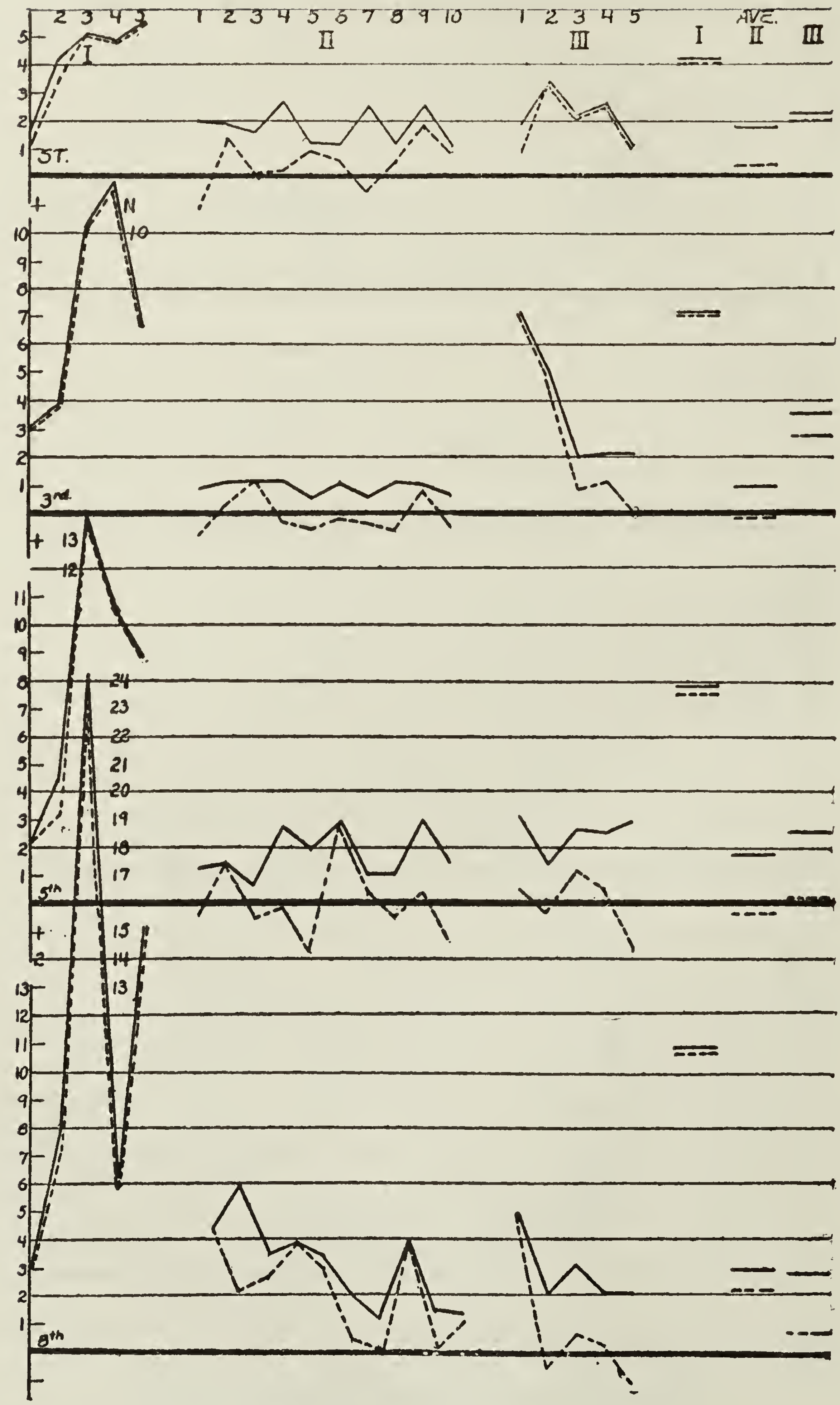

FIG. 5. Observer D, Alto; P. D., 3.2 dv.

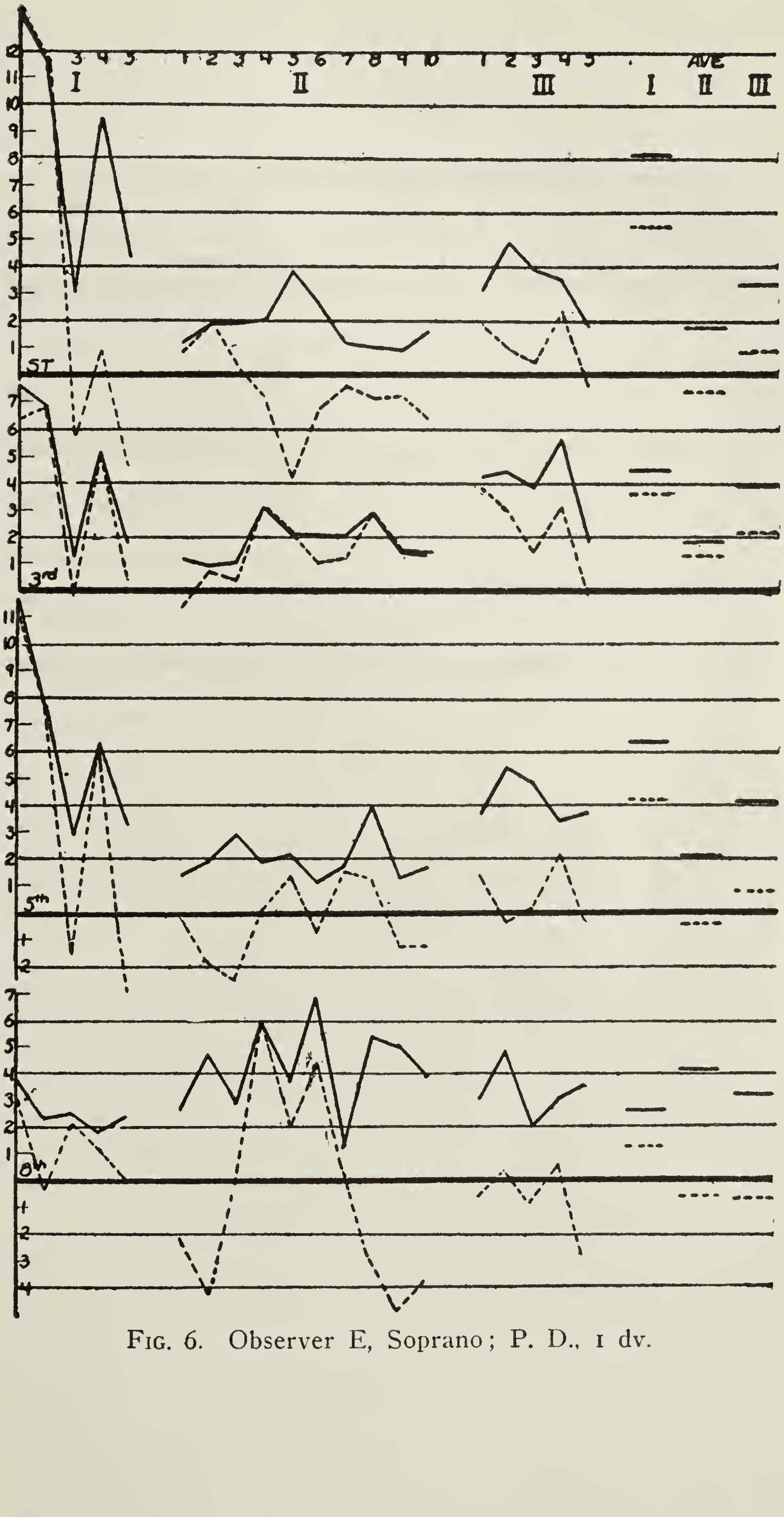

FIG. 6. Observer E, Soprano; P. D., 1 dv.

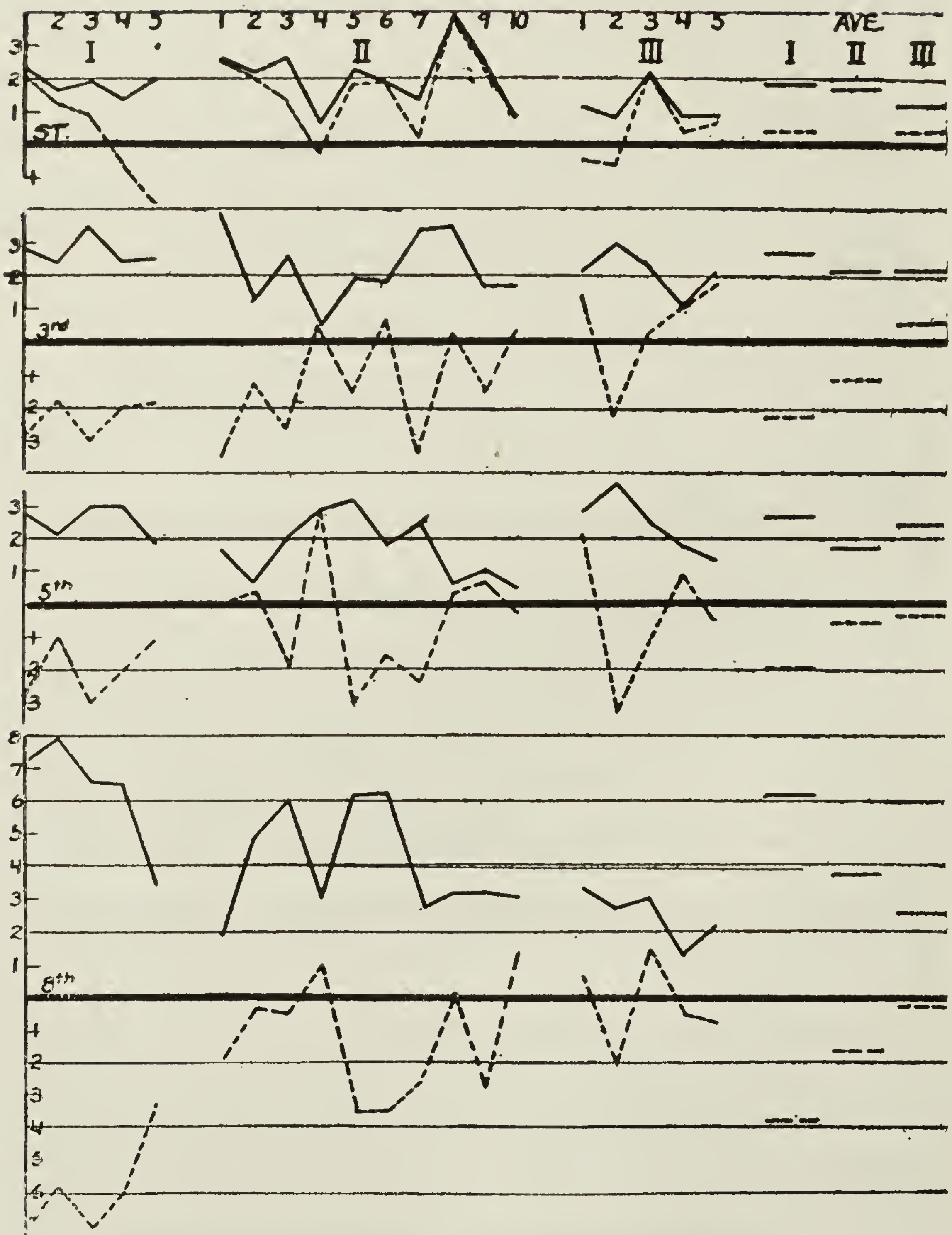

FIG. 7. Observer F, Alto; P. D., 3.3 dv.

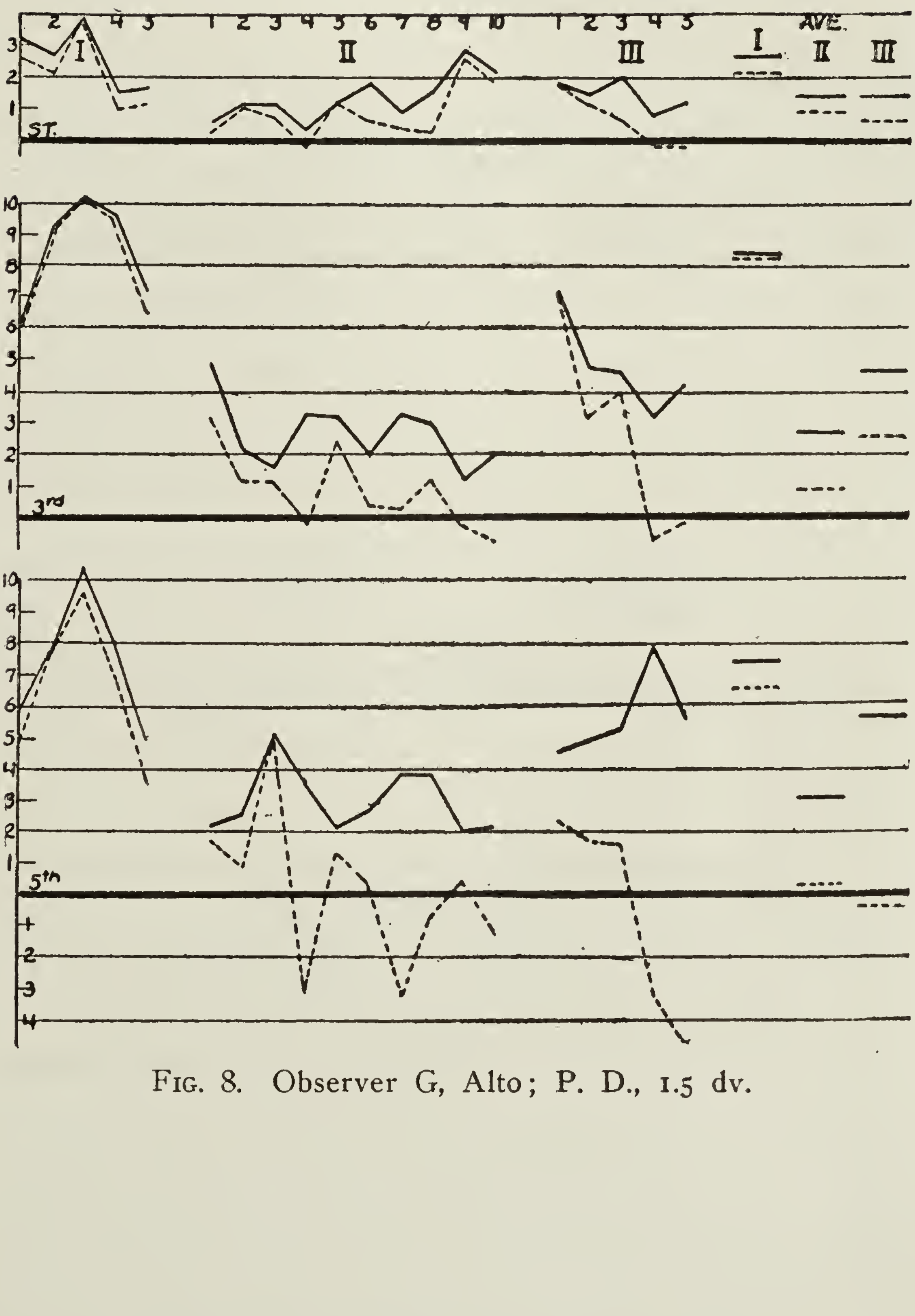

FIG. 8. Observer G, Alto; P. D., 1.5 dv.

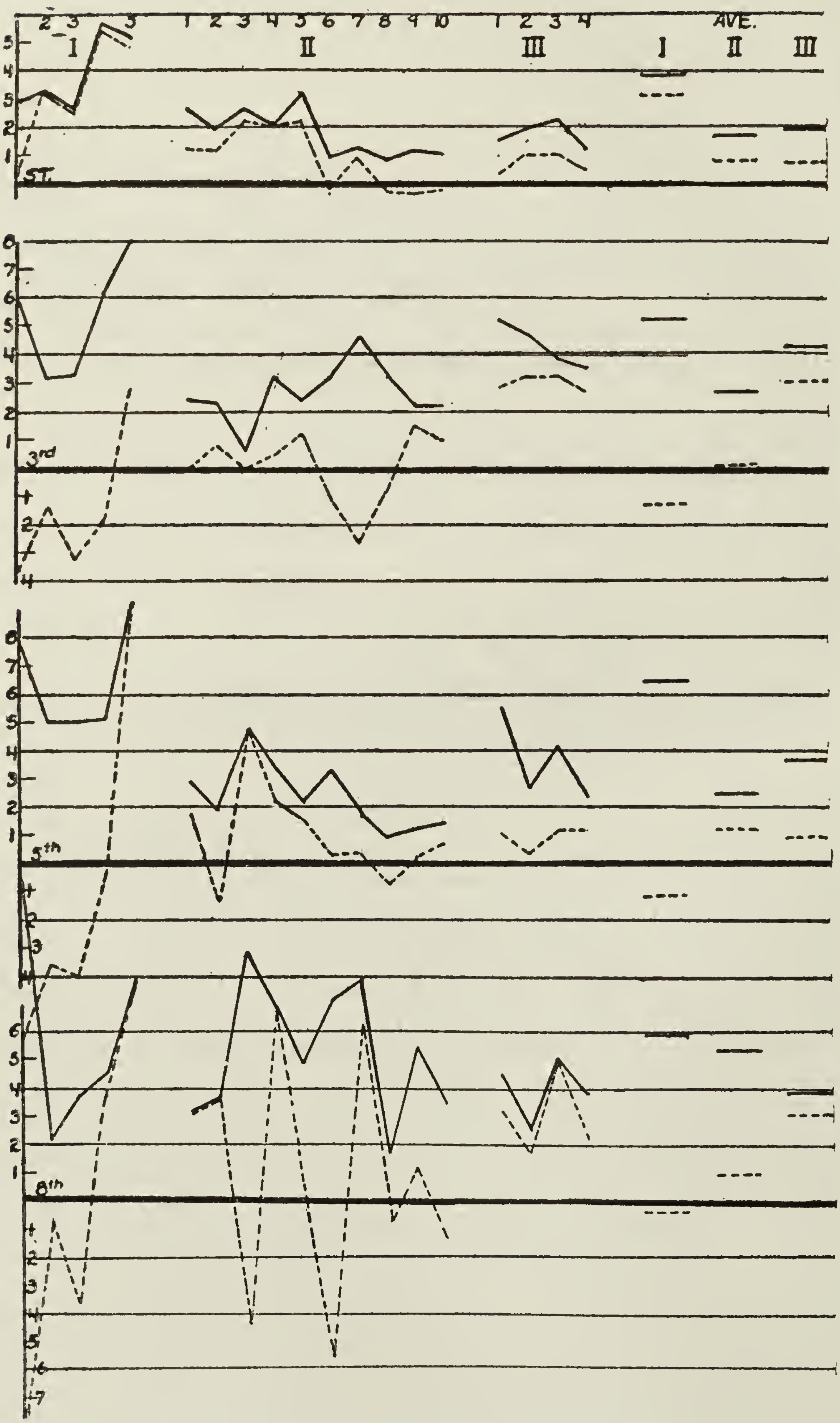

Fig. 9. Observer H, Soprano, P. D., .7 dv.

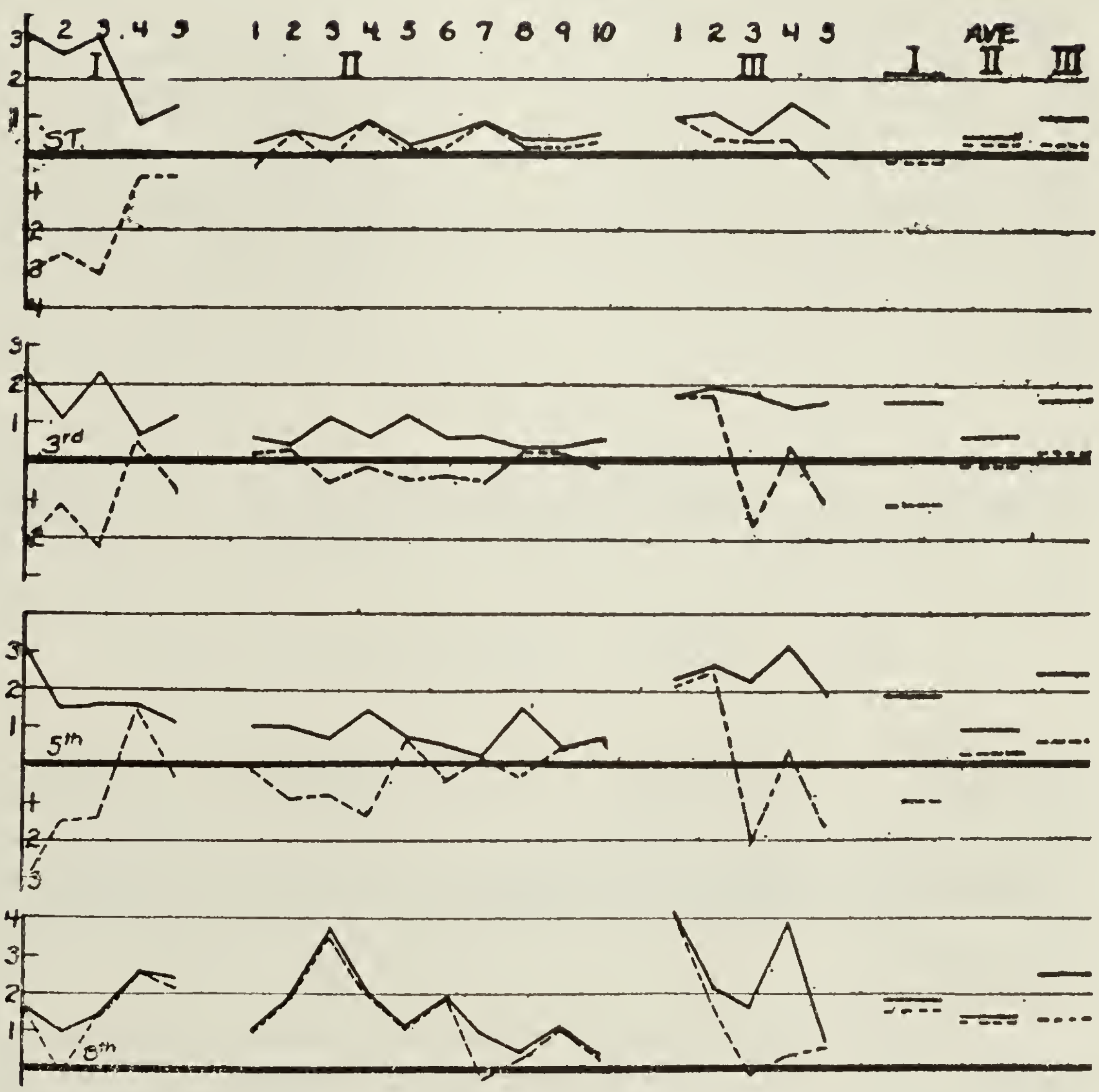

FIG. 10. Observer I, Tenor; P. D., 1.6 dv.

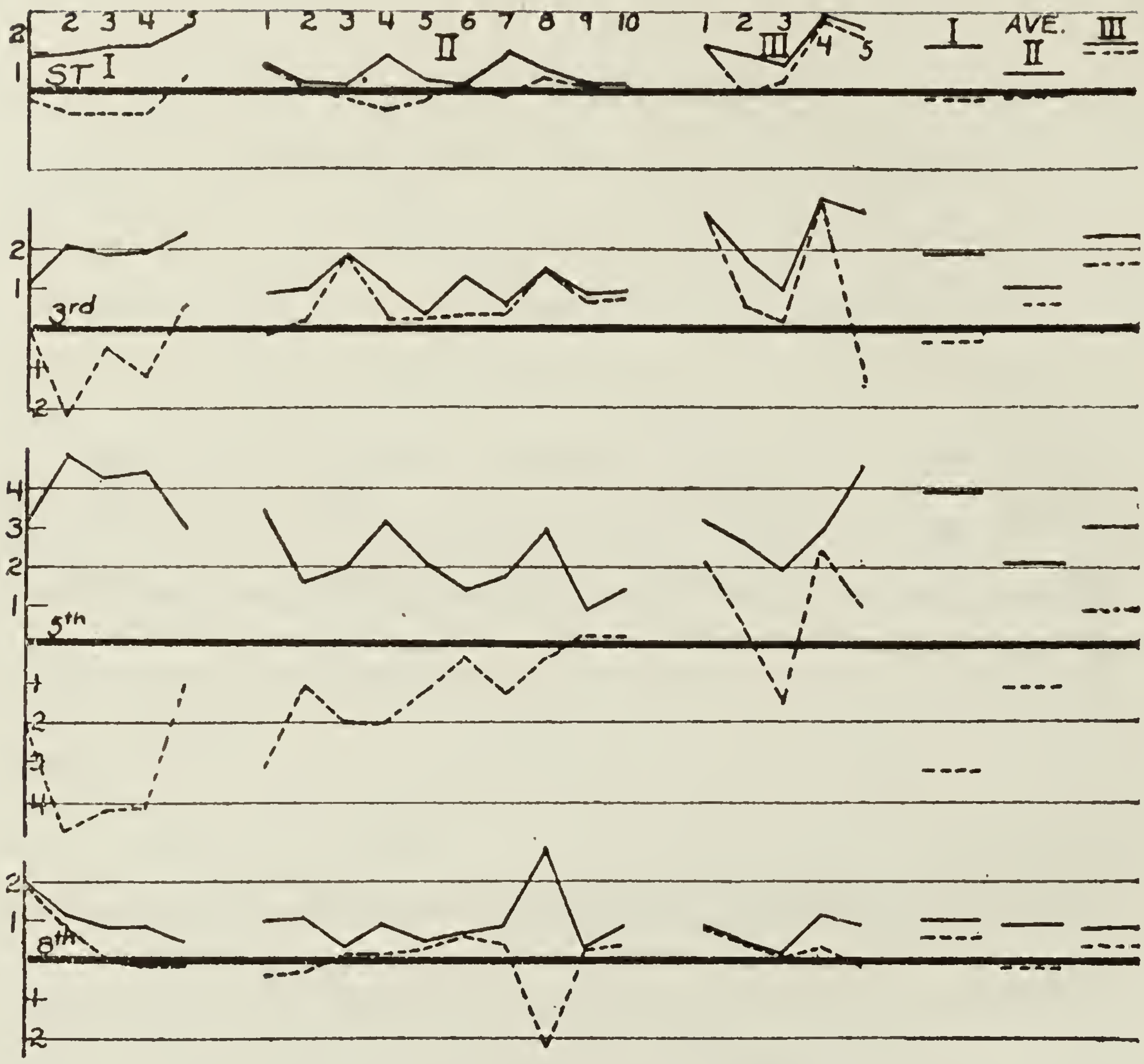

Fig. 11. Observer J, Baritone; P.D., .4 dv.

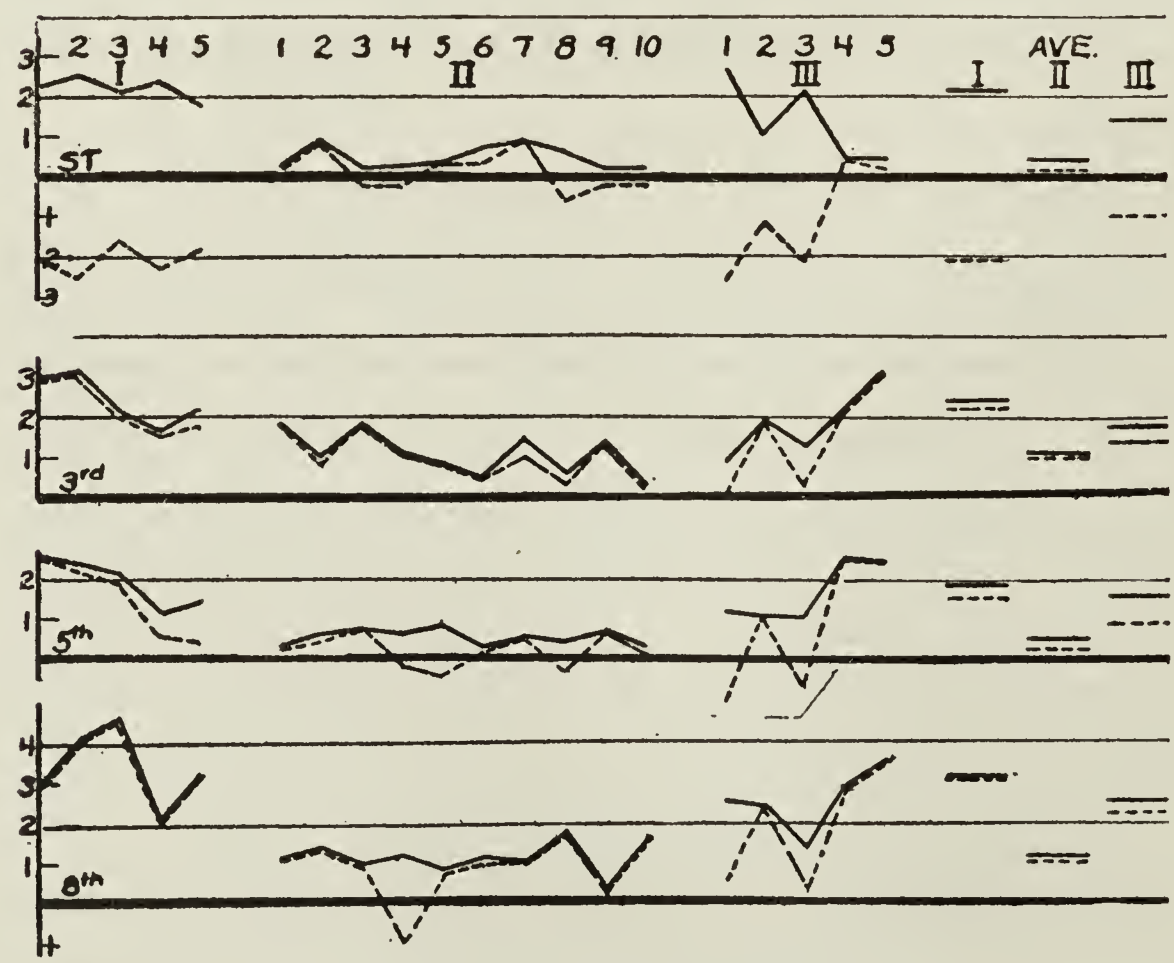

Fig. 12. Observer K, Tenor; P. D., 5 dv.

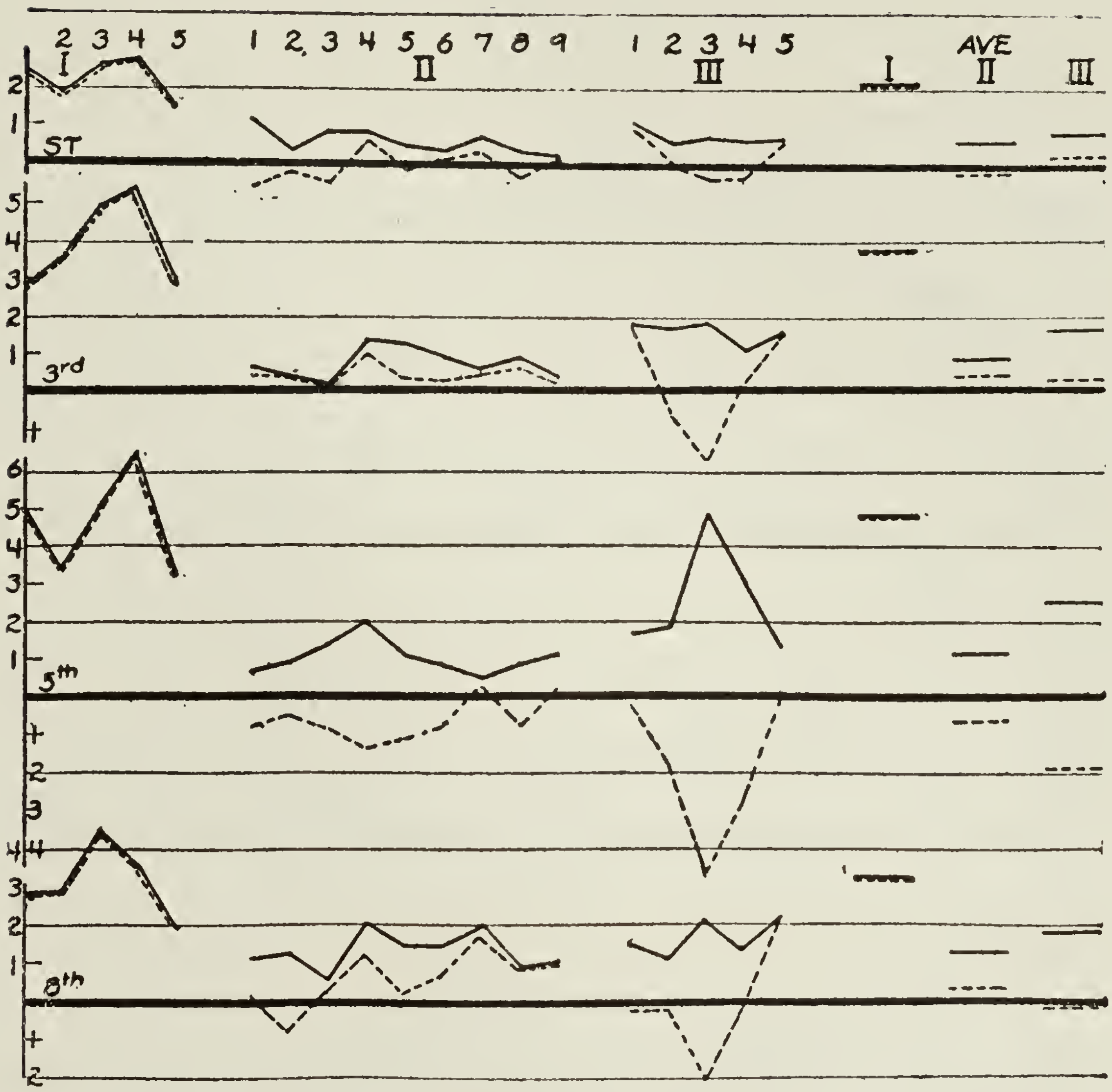

FIG. 13. Observer L, Bass; P. D., .9 dv.

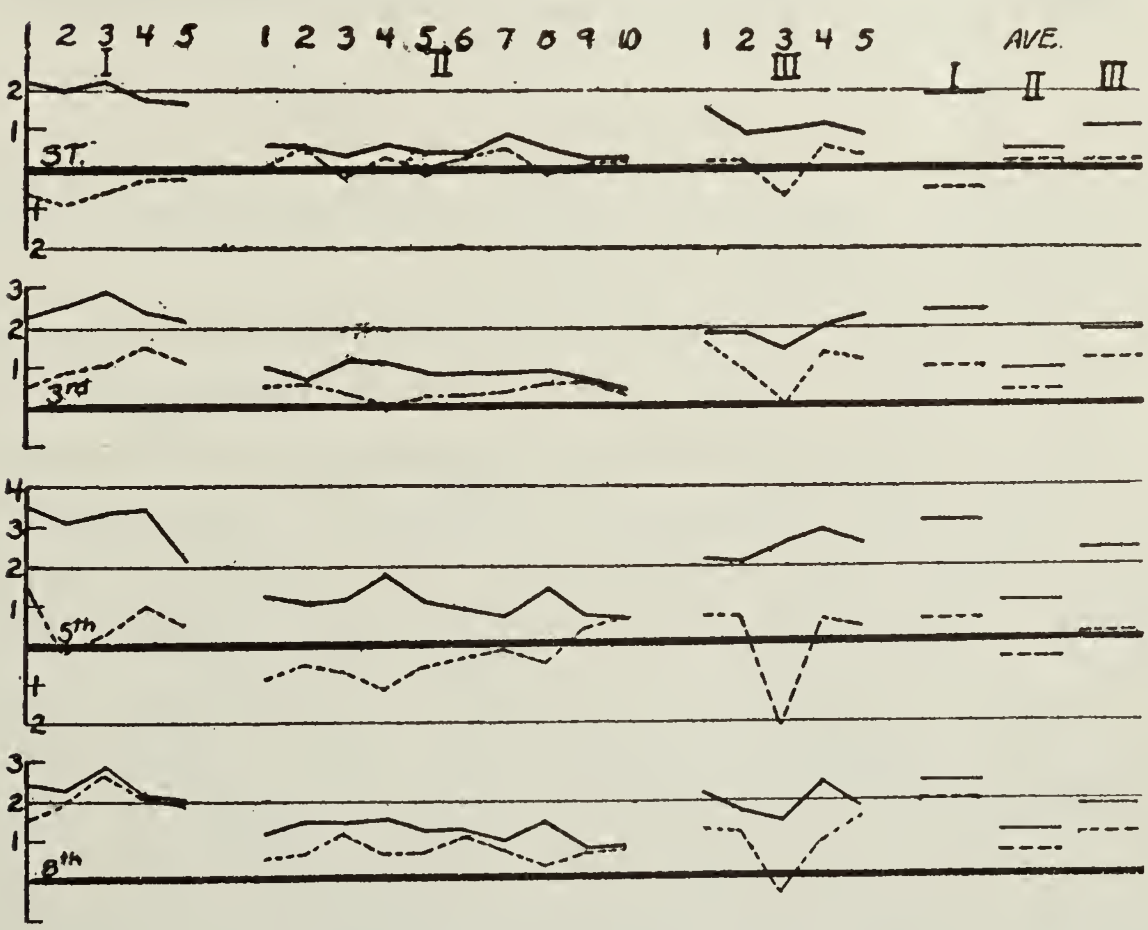

FIG. 14. Composite Curves, Men.

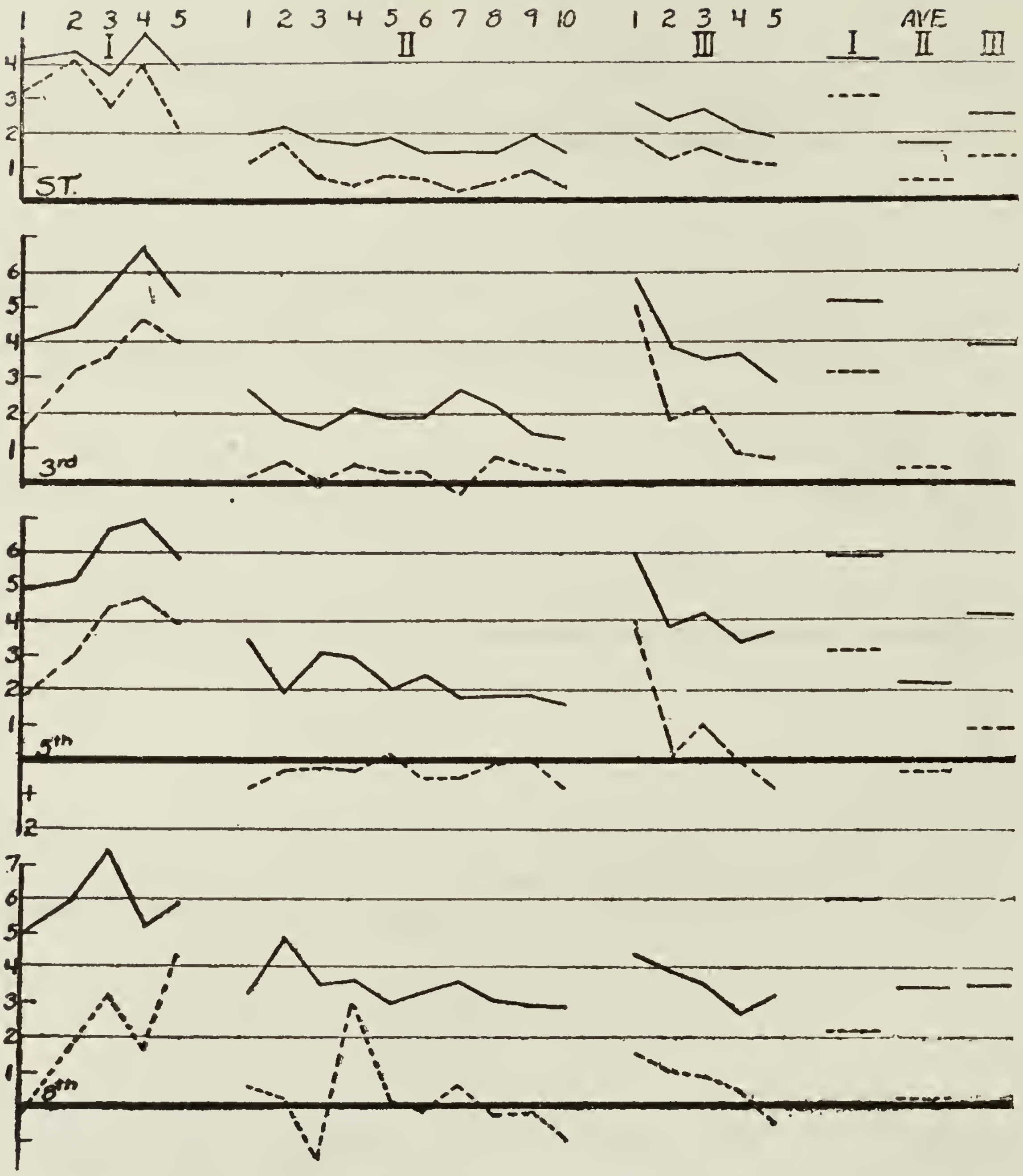

FIG. 15. Composite Curves, Women.

Observer *Kn* is a tenor and has had vocal training. His pitch discrimination threshold is about 1 dv.

These two observers practiced fifteen minutes daily for a period of fourteen weeks. Each observer practiced by himself, being both observer and experimenter, *i.e.*, he sang before the tonoscope and noted the pitch registered on the scale. Thus he perceived at a glance the errors in pitch and could modify his voice accordingly. No special order of singing was followed. The observer generally practiced one particular interval for a few minutes and then changed to another one. As a rule he spent the most time on the intervals least accurately produced. Once or twice a week a record was taken, the procedure then being the same as in Series I and III of the main series of experiments. The results are shown in Table III, and Figures 16 and 17.

Table III. *The Intensive Series*

Observer *J*

Day	Av.E. 1st	Av.E. 3rd	Av.E. 5th	Av.E. 8th	M. V. 1st	M. V. 3rd	M. V. 5th	M. V. 8th	C. E. 1st	C. E. 3rd	C. E. 5th	C. E. 8th
1.	1.1	3.4	3.4	1.3	1.2	2.0	2.7	1.3	.7	1.4	—1.4	— .1
2.	.8	1.7	1.4	.4	.6	1.7	.9	.4	.8	.5	—1.1	.4
3.	2.2	4.6	9.7	1.0	.8	1.0	.9	1.0	2.2	4.6	9.7	— .2
4.	.9	.6	1.9	1.8	.6	.6	.5	1.4	.9	.7	—1.9	—1.4
5.	.5	2.1	2.6	.6	.6	.9	.6	1.0	.5	—1.9	—2.6	— .6
6.	.9	1.9	1.6	.3	.6	1.9	1.3	.3	.7	— .1	.8	.3
7.	1.1	.7	1.2	1.0	1.8	.7	.8	1.0	1.1	— .3	—1.2	—1.0
8.	.5	.6	2.0	.6	.5	.6	1.2	.6	— .1	— .6	—2.0	— .4
9.	.4	1.4	2.1	1.0	.4	.6	1.1	1.0	.3	—1.4	—2.1	— .8
10.	.4	1.7	1.1	.6	.4	.7	1.1	1.4	.3	—1.7	— .5	— .6
11.	.5	.7	1.2	1.0	.7	.7	.6	.9	.5	— .1	—1.2	— .6
12.	1.9	2.1	2.5	1.5	1.3	.9	1.7	1.5	1.9	2.1	2.5	— .1
13.	1.3	1.5	2.9	.9	.5	1.1	2.3	.9	1.3	.9	1.3	— .5
14.	.1	1.6	2.1	.1	.1	1.0	.9	.1	.0	—1.6	—2.1	— .1
15.	.3	1.7	3.2	.6	.3	.6	.8	.8	— .3	—1.7	—3.2	— .6
16.	.1	1.8	2.5	1.4	.2	1.4	1.5	1.6	.0	.9	—2.3	—1.0
17.	.4	1.1	1.6	1.0	.4	.9	1.2	1.0	.4	—1.1	—1.2	1.0
18.	.6	.7	1.5	1.0	.5	.7	1.5	1.0	.6	.3	.3	1.0
19.	.5	1.2	2.0	1.3	.5	1.2	2.0	1.3	.2	.0	— .4	— .6
Av.	.7	1.6	2.5	.9	.5	1.0	1.1	1.0	0.6	0.05	—0.45	—0.3

Observer *Kn*

Day	Av.E. 1st	Av.E. 3rd	Av.E. 5th	Av.E. 8th	M. V. 1st	M. V. 3rd	M. V. 5th	M. V. 8th	C. E. 1st	C. E. 3rd	C. E. 5th	C. E. 8th
1.	.4	.9	.8	3.2	.4	.5	.9	2.0	— .3	.9	— .6	3.2
2.	1.1	2.2	.7	1.7	.5	.9	.5	.5	—1.1	2.2	— .5	1.7
3.	.2	1.4	.5	1.8	.3	.4	.5	1.6	— .2	1.4	— .1	1.4
4.	.3	.6	.6	1.0	.3	.4	.6	.6	— .1	.6	.4	.8
5.	.4	1.0	.5	3.0	.4	.4	.7	1.0	— .2	1.0	— .7	2.2
6.	.3	.9	.6	3.4	.3	.7	.6	1.8	— .1	.5	.4	3.4
7.	.6	.5	.5	2.2	.5	.5	.5	.6	.5	.3	.3	2.2
8.	.3	1.2	.7	2.6	.3	.4	.7	1.4	.3	—1.2	.3	2.2
9.	.5	1.0	.5	2.2	.5	.6	.5	.4	.4	.6	— .3	2.2
10.	.9	.7	1.5	1.8	.4	.5	.7	1.0	.8	— .7	—1.5	1.8
11.	.6	.6	.7	2.6	.4	.6	.7	1.4	.6	— .5	.1	2.6
12.	.5	.8	.3	3.2	.5	.6	.3	1.2	.3	— .6	— .3	3.2
13.	.8	.4	1.0	1.6	.3	.4	.5	1.2	— .7	— .2	— .8	1.2
Av.	.5	.9	.7	2.3	.4	.5	.6	1.1	.0	.3	— .3	2.2

Some Special Factors

Relation of pitch hearing to accuracy in singing. The coefficient of correlation (*r*, Pearson products-moments) between pitch discrimination and accuracy of singing was computed as shown in Table IV.

The relative absence of correlation here may at first seem incongruous. Three facts have to be taken into consideration: (1) that the limit of hearing does not operate until the average error is so low as to be affected by the limit; (2) the limit of hearing operated primarily only in the singing of the standard and possibly the octave; and (3) in singing the interval the concept of the interval presents other and larger variables than the discriminative hearing.

The two measures of discrimination and average error are not

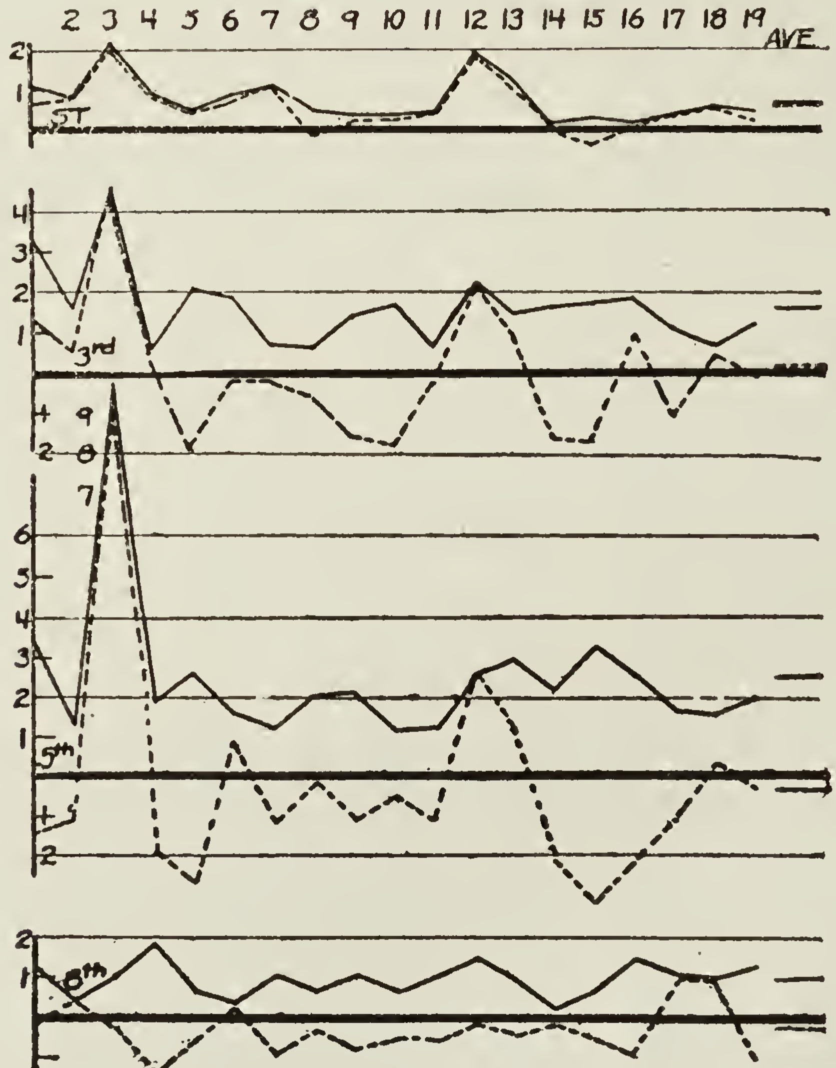

FIG. 16. Observer J, Baritone; P. D., .4 dv.

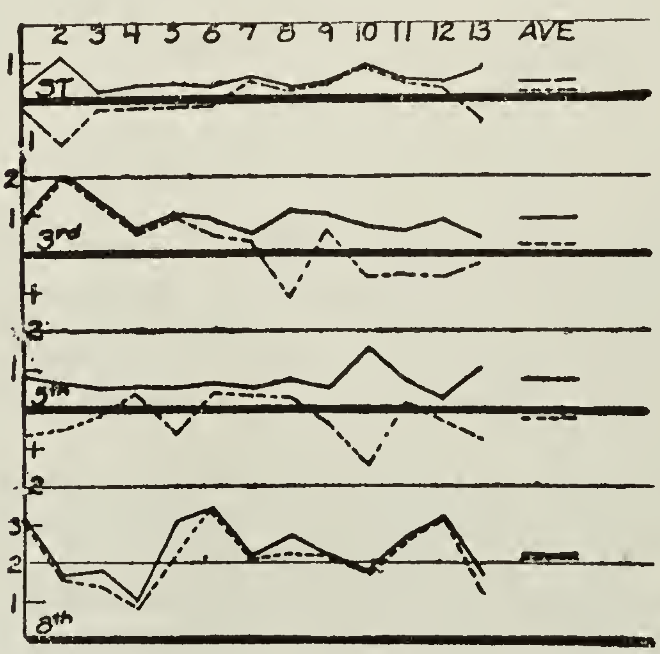

FIG. 17. Observer Kn, Tenor; P. D., 1. dv.

Table IV. *Correlation*

Correlation of pitch discrimination with—	r.	P.E.
Ave. Error of Standard, first series	o	
" " " " second "	.34	.17
" " " " third "	.08	.20
" " " Intervals, first "	.36	.17
" " " " second "	.08	.20
" " " " third "	.09	.20
" m.v. " Standard, first "	.12	.19
" " " " second "	.10	.29
" " " " third "	.0	.—
" " " Intervals, first "	.25	.18
" " " " second "	.08	.20
" " " " third "	.03	.20
Ave. Error of Judgment of standard, second series	.44	.16
" " " " " third, " "	.19	.19
" " " " " fifth, " "	.07	.20
" " " " " octave, " "	.21	.19
" " " Standard in last five tests. Series II	.67	.09
" m.v. " Standard " " " " Series II	.41	.16
" Error " Intervals " " " " Series II	.08	.20

comparable. We have no exact data on the relative value of these. Professor Seashore suggests that, until data are available, we may consider the figures in the discrimination records as of about double the value of the figures for the average error record; *e.g.*, if this were true, a person with a pitch discrimination of 2 dv. should after training be able to sing with an average error of 1 dv. On this interpretation it is evident that the threshold of discrimination was not an important conditioning factor in series 1.

There is little or no correlation between pitch discrimination, and average error in singing for the singing of the first series. The reason is obvious. They were not singing accurately enough to be hampered by the limit of hearing. The median threshold of hearing for these singers is 1.2 dv. The median average error in singing the standard is 2.7 dv.

If we turn then to the second series in which the average error was materially reduced to an approximate physiological limit, we find that the threshold of hearing asserts itself both in the singing of the standard and in the singing of the octave, particularly in the latter half of the second series in which the limit had actually been approached. Here we find the average error of the standard in the last five tests, *r*, .67, p.e., .09, and the correlation for the mean variation of the same is *r,* 41, p.e., .16. Correlation of error in judgment of average error for the standard in the second series, *r,* .44, p.e., .16, is significant. When we consider that there are many other factors besides the limit of hearing that condition the average error in singing even after training, this positive correlation would seem very reasonable as interpreting the facts.

The correlation of pitch discrimination with accuracy in singing of the interval is really not relevant for the reason that accuracy here depends primarily upon the precision of the concept or image of the interval; and theoretically pitch discrimination would in the main operate only in so far as it is significant of a general tendency to ear-mindedness. These considerations throw light upon the relative absence of correlation that Miles (4) found as his observers were all without special training, on the same basis as our observers in Series I. Had he trained them as in our Series II he would probably have found marked relationship between pitch hearing and performance.

The effect of difference in quality of the standard tone.—Miles compared the accuracy of reproduction of tones from the tuning-fork, the violin string, and the organ pipe, and found the following errors, respectively: fork, 1.6 dv.; string, 1.5 dv.; organ pipe, .9 dv. Commenting upon these results, he says: "Judging by the magnitude of the average errors, the record is in favor of the organ pipe. This is probably due to the fact that this tone is more nearly like that of the human voice. . . . From the observation it seems fair to conclude that richness favors accuracy in the reproduction of any particular standard." (2)

A number of other investigations have touched upon this point, but none of them are conclusive because the problem has not been isolated. Thus Klunder (3) and Cameron (2) used organ tones. The former found as the mean average error of his observers .47 dv., and the latter 6.6 dv. Berlage (1) had three observers imitating the human voice with the average error of .5 dv.

In order to determine the relative difficulty in reproducing the tone of the fork and the tone of the human voice, four women whose errors in imitating the fork had been found to range from 7 dv. to 12 dv. were given a special test, the result of which is given in Table V in terms of average error and constant error.

Table V. *Reproducing fork tone, own tone, and voice tone of another*

		Imitating fork		Imitating another person's voice		Imitating own voice	
	P.D.	Av.E.	C.E.	Av.E.	C.E.	Av.E.	C.E.
Wh.	1 dv.	8.8 dv.	8.8 dv.	2 dv.	2 dv.	.8 dv.	.6 dv.
Ilf.	2.3	7.4	7.4	.5	.2	.4	.4
Hu.	4.7	12.6	8.9	7.2	3.5	3.3	3.3
Co.	1	7.1	7.1	1.3	1.3	.6	.6

The results show in a striking manner what a marked effect the mere difference in tone quality of the standard makes in the accuracy of singing. The tuning-fork is found to be far the most difficult, and one's own voice the easiest to reproduce. In explaining this, one must take into account the actual differences in tone quality, the differences in familiarity with the respective tones, the differences in location, and the differences in volume; but most of all, the role of kinaesthetic imagery and kinaesthetic sensations.

Unfamiliarity with the pure tone of the forks with resonator may in part account for the large errors in the fork standard. However, in the case of Wh. this could not have been a strong factor, since she was one of the regular observers in the main experiment and had ample time to get accustomed to the fork. The fact that one can reproduce one's own tone more accurately than one can reproduce a tuning-fork does not prove that the latter is heard less accurately. It may be that there are certain normal illusions present in the hearing and the singing of one's own tone that are eliminated by the fact that the tone one hears is the same as the tone sung.

Relative accuracy of the different intervals. Table VI sums up the comparison of the different intervals for accuracy in our data. Those of Seashore and Jenner (6) are added for convenience.

In our figures the standard, the third and the fifth are sung with about equal accuracy, in terms of percent or part of a tone, and the octave is sung noticeably better. Seashore and Jenner's

Table VI. *Comparison of Intervals in Accuracy*

	Standard		Third		Fifth		Octave	
	dv.	%	dv.	%	dv.	%	dv.	%
Knock, 1914								
Men	1.2	8	1.7	8.5	2.2	9.1	1.8	5.6
Women	2.8	8.7	3.6	9	4.1	8.5	4.2	6.5
Seashore and Jenner, 1906								
Men	.8	5	2.1	10	2.9	12	3.2	10

(6) conclusion is that "The major third, the fifth, and the octave are approximately equally difficult intervals to sing. .... The average error expressed in terms of vibrations, as in the tables, shows that the difficulty of a natural interval varies approximately with the magnitude of the interval." The two sets of results therefore disagree on the standard and the octave.

A study of the mean variations in errors in the singing of the different intervals seems to further substantiate the conclusions just stated.

Table VII shows that the mean variations, in both the standard and the intervals, are similar to those of the average error; the percentages are about the same in the third and the fifth, and those of the octaves are the smallest. This, then, with the figures

Table VII. *Mean Variations for All Records in this Study*

	Standard		Third		Fifth		Octave	
	dv.	%	dv.	%	dv.	%	dv.	%
Men	.7	4.2	1.1	5.5	1.4	5.6	1.2	3.7
Women	2.	6	2.6	6.5	3.2	6.5	3.	4.7

of Seashore and Jenner (6) shows that, in musical terms, the third and the fifth are sung with equal precision but not with as high precision as on the standard and the octave.

In their study on minimal change in pitch in singing, Seashore and Jenner (6) found that the minimal change of pitch in singing the intervals varied in proportion to the magnitude of the intervals. The minimal change is a relatively constant fraction of a tone within this octave. This is true for both the aided and unaided series. If we reduce the records from vibrations to twenty-fifths of a tone, the minimal change is 3.1, 3.1, 3.6, 3.3, for the fundamental, the major third, the fifth and the octave respectively. This is surprising because within this part of a tonal range the pitch discrimination is normally measured by a constant vibration frequency instead of by constant part of a tone.

Table VIII. *Errors in Judgment of Errors in Series II*

	Standard		Third		Fifth		Octave	
	dv.	%	dv.	%	dv.	%	dv.	%
Men	.5	3	.7	3.5	.8	3.3	1.1	3.4
Women	1.6	5	1.9	4.8	2.3	4.8	2.9	4.5

It would appear from these results that accuracy in judging the errors of the different tones varies proportionately to the vibration frequency of the tone.

Similarity of the errors of the different tones. Another interesting fact to be noted in Series I and III is the similarity in the errors of the different intervals on a given day: if one interval is sung sharp or flat there is a tendency to sing the other intervals also with errors in the same direction. The greatest similarity is found in the third and the fifth; the constant error curves of the third and the fifth are similar in the case of every observer.

Since, in Series II, each tone was sung and practiced by itself a number of times and a complete break was made between the singing of the different tones, no common tendency was apt to be carried over from one tone to the other; and since efforts were constantly made to change the pitch of the tone, automatism was seriously interfered with. It is, therefore, not surprising to find that there was little or no similarity in the errors of the different tones and that there was a great variation in the reactions throughout this series.

Judging the difference in pitch of one's own voice and the pitch of the fork. Experiments in judging the pitch of another person's tones showed that the observers could discriminate much more accurately between the pitch of another person's voice and the pitch of the fork than between the pitch of their own voices and the pitch of the fork, the problem was to ascertain why this difference should exist. The following experiment was undertaken with the assistance of three women who had a tendency to sing 6 dv. to 14 dv. high when imitating the standard, in answer to the question, "Does a person who sings sharp or flat do so because he hears the pitch of the fork higher or lower than it is?"

A standard tone from the fork was sounded and the observer endeavored to reproduce the given tone. If the reproduced tone was sharp,—they all sang sharp,—a second fork was immediately sounded that was either the same as the standard fork or had the same pitch as the tone of the voice; *i.e.,* the second tone produced by a fork was either the same or lower than the pitch of the voice. The observer was then asked to judge whether the second fork was the same, higher, or lower than the pitch of the voice.

Table IX. *Comparison of Tuning Fork and Voice*

	When the second fork was the same as the standard, it was judged,			When the second fork was the same as the voice, it was judged,		
	Same	Higher	Lower	Same	Higher	Lower
Ilf.	56%	36%	8%	16.6%	79.2%	4.2%
Hu.	58%	25%	17%	23.3%	68.4%	6.3%
So.	61.5%	11.5%	27%	0	100%	0
Ave.	58.5%	24.2%	17.2%	14.3%	81.9%	3.5%

The results show that when the standard fork was also sounded as the second fork, although it was generally 6 dv. to 14 dv. lower than the tone of the voice, its pitch was judged the same as the pitch of the voice in 58% of the cases, higher in 24% of the cases, and lower in only 17% of the cases. When the second fork had the same pitch as that of the voice, it was judged higher than the voice tone in 81% of the cases, same in 14% of the cases, and lower in 3.5% of the cases. These results indicate quite positively that there was a tendency on the part of these observers either to hear the fork higher than the voice or the voice lower than the fork.*

* Editor's Note: After the presentation of concrete data, the original article contains an analytical study of the sensory, central and motor process which condition and limit or facilitate acquisition of skill as in singing true pitch. However, during the delay in publication, on account of the war situation, such new turns have been given to some of these problems by Dr. Knock's successors in the laboratory that publication of that section is deemed inadvisable at the present time.

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A SURVEY OF MUSICAL TALENT IN A MUSIC SCHOOL[1]

By

Esther Allen Gaw, Ph. D.

The tests employed; plan of presentation; systematic inquiry; teacher's rating; Case A; Case B; general tendencies of capacities in music students; brief mention of individual cases; some practical suggestions; bibliography.

The measurements, of which this paper is a discussion, were made from a group of music students in the School of Music of Northwestern University in the autumn months of 1918. The tests were started with thirty observers but through sickness four of these did not complete the series. The students were women of from seventeen to twenty-five years of age, who had been in the conservatory from one to four years. An attempt was made to get some who had been particularly successful and some who had been unsuccessful. The ones who were judged as unsuccessful were chosen largely on account of failure in ear-training classes. Unfortunately two of those who

[1] *The Editor's note*—The following paper is an extract from a much more extensive paper presented as a thesis for the doctorate in 1919. The section here presented aims to show merely what procedure was devised and used in the study of talent in a music school, with particular application to the resulting description of an individual's talent. For each of the twenty-six pupils examined, a talent chart was made and on the basis of this, with supplementary information as described, a plain statement is made for each case. These statements are limited to the recital of the facts gathered as they should be given to the music teacher in the way of information about the pupil.

As all that we aimed at was to try out and illustrate the technique of procedure, only two of the twenty-six individual reports are here published, and these merely as samples of the method. The original paper contained a number of additional studies which will be published separately either by the author or by other collaborators in the laboratory. For those who are interested in installing talent rating in music schools, it should be said that investigation of this procedure has been continued during the last three years and a fuller procedure, revised up to date, will appear in the next volume of these Studies.

C. E. S.

showed an inability to cope with the problems in ear-training, and whose measurements would have been interesting from a diagnostic standpoint, did not complete the tests on account of sickness.

These tests have been used in various forms in the Psychological Laboratory at the State University of Iowa. The natural capacities of many people, including music students, have been measured, with the result of affording helpful advice; but this is the first effort to secure any considerable number of measurements in any given school. The task of testing a number of those who have decided to study music seriously was undertaken with two ideas in mind: (1) to find out how the music students would rank in the various forms of the test, and (2) to develop a procedure in talent analysis which would be of service in the music schools where they might be used.

The tests employed

Auditory Acuity—a test of the sensitiveness to sound in each ear as measured by means of the Seashore audiometer (10, p. 90).

The Sense of Pitch—a test of the ability to hear differences in pitch, 200 trials given with tuning forks by the group method (9, pp. 21-60).

The Sense of Intensity—a test of the ability to hear differences in loudness, 200 trials given with the audiometer by the group method (10, p. 95).

The Sense of Time—a test of the ability to hear differences in the duration of time intervals, 200 trials, or 40 trials each on the differences of .20 sec., .14 sec., .09 sec., .05 sec., and .02 sec., given by means of a telegraph click, by the group method (10, p. 108).

The Sense of Consonance—a test of the ability to hear the relative consonance or dissonance of two notes sounded simultaneously, 100 trials given with the piano by the group method (10, pp. 155-156).

Simple Reaction to Sound—a test of the ability to react to a simple click heard in a telephone receiver, 20 trials measured by the smaller chronograph (10, p. 170).

Complex Reaction to Sound—a test of the ability to act with discrimination and choice to two sounds clearly distinguishable in intensity, 15 reactions to the faint sound (10, p. 170).

Motor Reliability—a measure of the comparative steadiness of reaction based upon the mean variation in simple and complex reaction.

Auditory Serial Action—a test of the ability to act with discrimination and choice in a continuous series with auditory stimuli, five series of seventy-five reactions, measured by means of a device such that the four sounds were made successively by the motion of a carriage of a typewriter on which the observer recorded the proper responses (4 and 6, pp. 1-17).

Visual Serial Action—a test of the ability to react to visual stimuli, five series of seventy reactions measured as above except that the stimuli were visual (4).

Free Action—a test of the ability to mark time at a uniform rate, 10 records after training, measured on the chronograph (9, pp. 175-176 and 2, p. 335).

Timed Action—a test of the ability to keep time with a sound recurring at the rate of one per second, 10 records after training, measured as above (10, p. 175).

Rhymthic Action—a test of the ability to mark the rhythm, 30 trials, recorded by the graphic method with the chronograph and measured by that instrument (10, p. 175).

Grip—a test of strength, the best record of three trials of the strongest hand, measured by the Smedley dynamometer (13, p. 101).

Precision—a test of accuracy in direction of movement, 30 trials with the right hand measured by means of a steadiness gauge and a needle completing an electric circuit, somewhat as described by Whipple (13, p. 157).

Singing Key—a test of the ability to sing the tone d, 290 d. v. sounded by tuning forks, 30 trials, measured by the tonoscope (11).

Singing Interval—a test of the ability to sing the intervals in the first two measures of America, and the major third, 10 trials of each measured as above.

Control of Voice—a test of the ability to sing small differences in pitch, 20 trials measured as above (11; 5).

Range of Voice—estimated by the singing teacher of each student.

Quality of Voice—an estimate of the comparative tone quality of the voice, made by the teacher rating his pupils as described in the questionnaire for teachers, below.

Auditory Imagery—a test of the ability to image auditory sensations measured by the introspection of each observer, group method, 20 trials as described by Seashore (10, pp. 219-220).

Visual Imagery—a test of the ability to image visual sensations, measured by the introspection of each observer, 21 trials, as described by Seashore (8, p. 107).

Motor Imagery—a test of the ability to image motor sensations, measured by the introspection of each observer, 10 trials as described by Seashore (8, p. 108).

Tonal Memory—a test of immediate memory of nonsense groups of tones, 150 trials given on the piano (10, p. 239).

Auditory-motor Learning—a test of the ability to learn as shown in auditory serial action given on five successive days.[2]

[2] The median time for the response to the 75 stimuli in auditory serial action was 64.9 sec. on the first day, 52.3 sec. on the second day, 47 sec. on the third day, 43.6 sec. on the fourth day, and 41.4 sec. on the fifth day. The median number of mistakes for the first day was 5.4, for the second day 4.1, for the third day 4.4, for the fourth day 5.0, and for the fifth day 5.6. Some observers made more than the average number of mistakes and some made less. It was desirable to credit those who made a small number of mistakes and to debit those who made a large number. To do this it seemed fair to take off for each error in excess of the median error, as much time as is required for each response. The median time for the series of seventy-five trials on the first day was 64.9. It therefore took one seventy-fifth of 64.9 sec. for each response, or 0.87 sec. Dividing the median time of the other four days by seventy-five we find that each response on the second day required .70 sec., on the third day .63 sec., on the fourth day .59 sec., and on the fifth day .54 sec.

If the observer made one error more than the median error on the first day .87 sec. was added to her time record for that day; if she made two errors less than the median error 1.7 sec. was subtracted from her time record. In this way a weighted time record for the five days was obtained. A percentile rank table on the basis of the median time record as average, or 50 percentile rank, was then established for each day separately. These are the ranks which are used in discussing the learning power of each individual.

Visual-motor Learning—A test of the ability to learn as shown in visual serial action.[3]

Intelligence—a measurement of general intelligence by means of the Stanford revision of the Binet test (12).

All of the measurements were reduced to percentile rank; *i.e.*, rank on a scale of one to one hundred, one being the lowest rank obtainable in any measurement, 100 the highest and 50 exactly the average. The results in all the tests have been reduced to this common basis and are thus comparable (10, p. 15).

For the greater part of the measurements the norm of percentile rank was that of a large group of adults as shown in the following table:

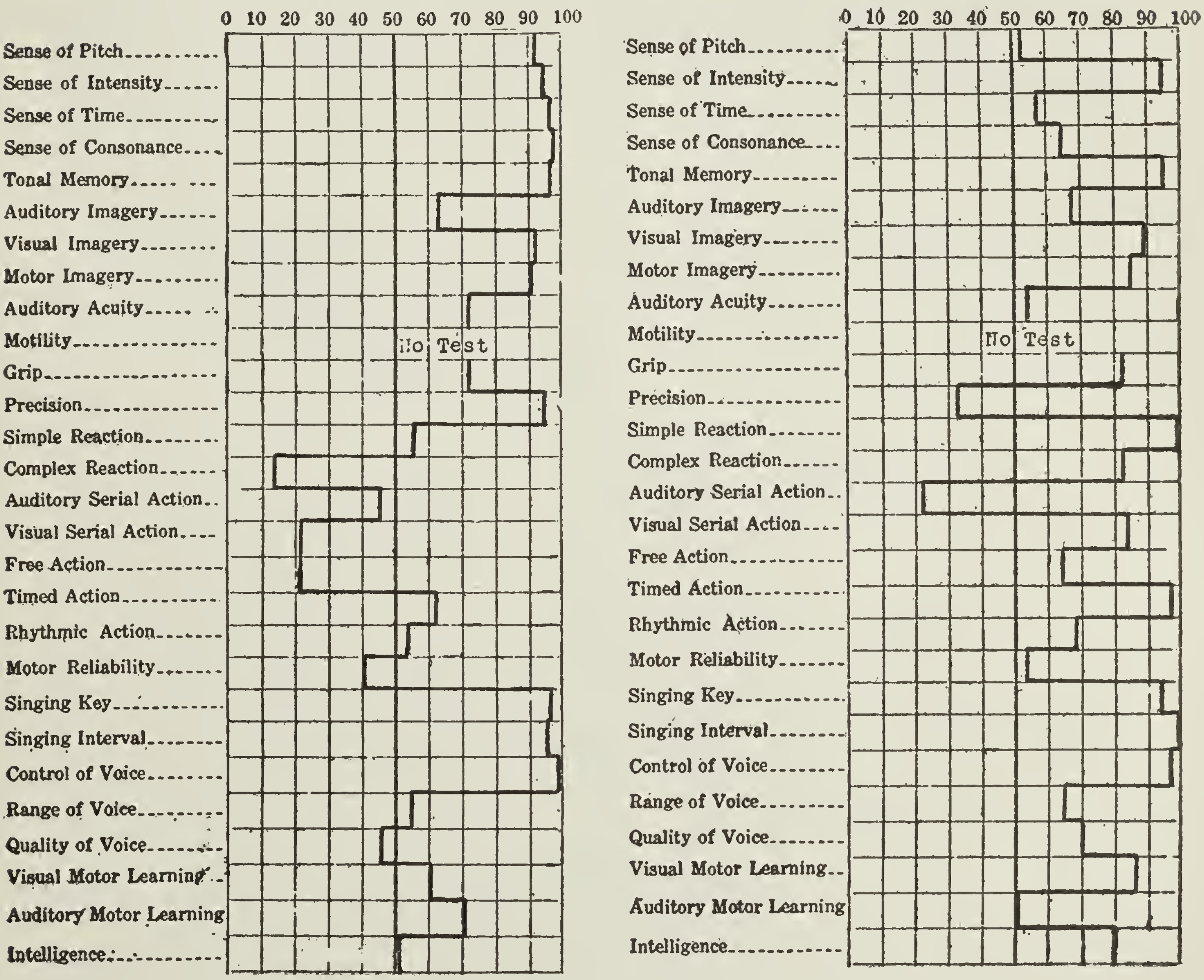
Test	No. of cases	
Pitch	1265	
Intensity	365	
Time	237	
Consonance	248	
Free Action	275	
Timed Action	275	
Rhythmic Action	275	
Grip	26	
Whipple adult norm		
Precision	57	(women)
Singing Key	158	(women)
Singing Interval	158	(women)
Control of Voice	158	(women)
Auditory Imagery	339	
Visual Imagery	339	
Motor Imagery	339	
Memory	275	

The records in simple and complex reaction were given approximate rank by reference to distribution in various groups of records on reaction time. Auditory and visual serial action had to be ranked by themselves because this was the first attempt to get a large number of women's records and we had no norms for women. The same is true of the learning curves obtained for the successive trials in these two tests.

[3] The median times for visual serial action were arranged in exactly the same manner as those for auditory reaction, being for the five respective days 51.5, 44.9, 41.4, 40.6 and 39.5 sec. The median number of errors for the five days is 5.5, 4.2, 4.4, 4.5 and 4.6. The weighted time record for each day was obtained just as in auditory serial action and the visual learning determined upon the basis of the weighted records of each individual.

The charts used as a graphic illustration of each individual measurement are made from the percentile rank grades. The tests are listed at the left. The figures at the top of the graph indicate percentile rank which is shown by a vertical line in a square opposite the corresponding test. The line beneath 50 is made heavy in order that the measurements above and below average may be identified immediately. (See Fig. 1).

The time taken for giving the test amounted in all to about



Case A. Case B.

FIG. 1. Two musical talent charts.

eleven hours for each observer. This was taken up in twelve personal appointments of one-half hour each, six group tests lasting about forty-five minutes, and one hour appointment for the giving of the intelligence test. Each student came usually twice a week.

The measurements seem reliable on the whole. The conditions for giving them were favorable. The students were intensely interested and eager to put forth their best effort every time they came to their appointments. There was time enough to verify the group tests and examine their results when internal evidence indicated that the true physiological threshhold (9, p. 49) had not been found. Students were always excused and given another appointment when it was realized that they were not in the proper physical condition for the test. There was in general hearty co-operation of the faculty and of the students.

Plan of presentation

In order to understand the discussion of the individual musical talent charts it is advisable to consider in a preliminary way some of the facts that will be general in all. Each student will be discussed according to the following outline:

I. Musical History of the Family
II. Personal Musical History
III. Musical Sensitivity
  A. Simple forms of impression
    1. Sense of pitch
    2. Sense of intensity
    3. Sense of time
    4. Sense of extensity
  B. Complex forms of impression
    1. Sense of rhythm
    2. Sense of consonance
    3. Sense of timbre
    4. Sense of volume
IV. Musical action
    1. Simple reaction
    2. Complex reaction
    3. Motor reliability
    4. Auditory serial action
    5. Visual serial action
    6. Control of pitch
    7. Range and quality of voice
    8. Control of time and rhythm
    9. Grip and precision
V. Musical memory and imagination
    1. Auditory imagery
    2. Visual imagery
    3. Motor imagery
    4. Creative imagination
    5. Memory span
    6. Learning power
VI. Musical intellect
VII. Musical feeling

Systematic inquiry

The manner of calculating the number of lessons and the time spent in practicing and playing is shown in the following questionnaires. The questionnaire for the musical case history of each student was filled out in individual conference with the examiner. In this way there could be no misunderstanding about the meaning of each question, or about getting all the information that was desired. It was possible to follow up matters of special interest and meaning with each student. The points in the following questionnaire were always brought up by the examiner so that the information about each student should cover the same facts.

I. Musical Education
  1. Voice—early indications of musical ability
    a. Public school instruction
    b. Private lessons
      Number of hours of lessons
      Number of hours of practice
      Number of hours of playing
    c. Glee clubs
  2. Piano—private lessons in the home
    Number of hours of lessons, practice and playing
    Playing for orchestra
    Playing for glee clubs
    Appearance in recitals

II. Environment
  1. Family—Particulars about musical interests of each member
    How much family music?
    Does family encourage or discourage music?
  2. Community—Encouragement in musical interest by individuals outside of the family.
    Opportunity to belong to chorus or orchestra.

III. Character of performance
    What do you play now?
    Programs of concerts, if possible
    What do you sing now?
    How much practice now?

IV. Dominant interests and ambitions
    What do you like best now?
    What do you like best to play or sing?
    What would you like to do with music?

V. Emotional reaction
    What kind of music do you like best to hear?
    How does music affect you?

VI. Creative imagination
  a. Spontaneous unstimulated making of melodies or harmonies
  b. Ability to compare melodies and arrange music harmonically for classes
  c. Extemporizing on the piano or organ or any other instrument

Teacher's rating

The questionnaire for the teachers was also gone through personally with each teacher with a few exceptions thus securing a good understanding. The estimate of each teacher on his student's ranking was interesting. Each one showed an interest in the evaluation of his pupils and a coöperation which made this part of the examination very easy. This questionnaire read as follows:

Kindly rank all of your pupils into five groups on the basis of the five following points:

A.	The highest ten per cent.........	91-100
B.	The next twenty per cent........	71- 90
C.	The average forty per cent	31- 70
D.	The low twenty per cent	11- 30
E.	The lowest ten per cent	1- 10

Suppose that you have thirty students and that you are ranking them on Application. Take the three who are best in Application and give each a grade shown by A. Take the three poorest and give each a grade shown by E. Then take the six who are the next best to the A's and give them each a grade of B, and the six who are just better than the E's and give them a grade of D. The twelve who are left will be the average ones who should receive the grade C. Let me know your estimates of the pupils whose names I give you. Please follow the above described procedure in giving the students grades on the following six points. In this ranking each point must be considered separately. Make the ranking for Application and then begin all over again and make the ranking for Achievement, etc.:

1. *Application.* How does the student rank as to being conscientious about practice and preparation?
2. *Achievement.* What is the ratio of the student's proficiency to his opportunity?
3. *Ambition.* Is the student eager to excel and does she work to excel?
4. *Ability to read music.*
5. *Ability to memorize music.*
6. *Quality of voice.*

Please make descriptive comments without ranking on the following points:

1. Estimate of comparative preparation when the pupils came to you.
2. *Strong and weak points of the student.* Among other things, speed and accuracy learning.
3. *Dominant interests.*
4. *Character of performance.* Appeal to hearers by technique or tone? Does she have a good stage presence?

5. *Emotional reaction to music.*
6. *Range of voice.*

Kindly supplement each of the above points by any comment of the individual which seems interesting or enlightening.

The following are detailed analyses of the measurements of two of the music students whose talent charts are shown in Fig. 1:

Case A.

Musical History of the Family: The family on A's father's side was musical. Her father sang very well and loved to sing. When a boy he played the violin well. His family had more than the ordinary amount of music in the home. He died when A was ten years old. An aunt, the sister of A's father, played the piano exceptionally well. A's mother is not musical. She loves to sing but cannot carry a tune if some one else sings alto. A's grandmother on her mother's side, however, still plays the piano occasionally although she is seventy-six years old. The grandfather on this side disliked music so intensely that A could not satisfy her desire to play the beautiful piano at his home.

Personal Musical History: When A was a little child she loved to hear music and would beg people to play for her whenever she entered a house where there was a piano. She did not, however, sing very much at that time. At the age of ten she began to study the piano with a rather inferior teacher whom she liked very much. She studied with this teacher for two and a half years acquiring some knowledge of music and some undesirable musical habits connected therewith. She then studied with another teacher until she entered the University. This teacher was really musical and a thorough teacher in some ways although he attempted to force her too rapidly. She could not do the things he wanted her to do.

During her second year in high school A took nine months of singing lessons. She sang in the High School glee club for four years, and in the school operettas, taking part, indeed, in all its musical activities.

At the very beginning of her piano lessons A attracted the favorable attention of a music supervisor who encouraged her parents to give her special musical advantages. Her second piano teacher also encouraged her and thought of her as one of his very best and most promising pupils. In spite of this fact she has had fewer lessons than the usual girl who enters the conservatory. It must always be borne in mind however that this is more than the average in an unselected group. She has also fewer than the average number of hours of practice and playing to her credit. She is now twenty-one years old. She has played in church and Sunday school for many years but has never played accompaniments either for glee clubs or for singers.

Musical Sensitivity: A's acuity of hearing is slightly above the average. In the other simple forms of sensory impressions she is most excellent; her rank in pitch, intensity, and time discrimination is very high. This means that she can hear very small differences in the pitch of tones, in the comparative loudness of tone, and in the duration of tones. As far as the recognition of small differences in pitch, intensity, and time are concerned, A has the highest kind of capacity. In the more complex forms of appreciation she is somewhat variable. Her judgment of consonance is very high and indicates that she has a feeling for harmonic values. In ear training classes, however, she obtains only average grades, probably due to her average intelligence. Her perception of rhythm, shown in her rhythmic action, is average. Her sense of extensity, sense of timbre, and sense of volume, dependent as they are upon pitch and intensity, are doubtless very keen.

Musical Action: In the simple reaction test she is average, which means that she can make the proper motion in response to a sound with average quickness. But her reaction when she has to make a choice of two sounds is below the average. This rating may not be fair to her for in auditory serial action, where a choice has to be made between four sounds, with the proper response for each, we found her to be average. In visual serial action, which is an index of the power to respond to a visual symbol, she is inferior. Both auditory and visual serial action will be discussed again under learning. A's general motor reliability is slightly below average. This means that she can act fairly accurately and without much variation in the reliability of her motions.

In the motor control of her voice A is better than in that of her hand. Her rank in each of the three tests which indicate this fact is of the very highest kind. Accordingly we should expect her to sing very accurately and to control her voice in very small differences of pitch, which she does. This correlates well with her keen sense of pitch. The range of her voice is average and the quality average. Her control of time and rhythm is average on the whole. Her timed action and her rhythmic action are slightly above the median, but in free action she is inferior.

We find that there is very little connection between the sense of time and free action. Free action is more dependent upon motor response than upon auditory perception of time relationship. In timed action and in rhythmic action A is better than in free action. This is entirely consistent since there is more relationship between time sense and rhythmic action than between time sense and free action, and still more between time sense and timed action. The comparatively low ranks which A obtains in all of these tests are consistent also and denote A's low power of motor response. Since her timed and rhythmic action are average she will be able to play music with average accuracy in time and tempo. Rhythm will not, however, be a conspicuously marked characteristic of her playing.

A's grip shows the physical strength necessary for a pianist. Her rank in precision is better than that of her other motor and reaction tests. It may be possible that she should have done better in all of these motor tests. She had been ill for two weeks. But even supposing these ranks to be too low, they are probably correct in so far as they serve to indicate that A is comparatively slow in her motor coördination.

Musical Memory and Imagination: In auditory memory A is of very high rank. Her auditory imagery seems rather low when compared with the other kinds of imagery. She possibly should have rated herself higher in view of her exceeding keenness in pitch, time and intensity.[4]

[4] The imagery tests were given to the group of music students according

A's visual imagery is of high rank, although her sight reading on the piano is average. She has the visual image of the notes, perhaps, or of the motions which she is about to make, but cannot put it into action. Her sight singing is superior. This is the result of her superior motor ability in pitch singing. The difference between her sight reading on the piano and that in singing is the very difference which exists in the motor ability of her arms and hands and that of her vocal cords.

A does not compose melodies spontaneously. Sometimes when she is at the piano she makes up a tune and tries to see how she can harmonize it, but not very often. She finds it easy to make up melodies for her harmony and composition. She seems to be normally inventive in musical composition but not essentially of the creative type of mind musically.

A's immediate memory for tone is very good; she can re-

to the procedure of Agnew, with the important difference that the Iowa students worked out their imagery ranks by themselves after general instructions given to the class as a whole (1). There was no opportunity for each student to consult with the instructor about the ranking. With the music students, however, each individual student was given a thorough training in the comparison of images and the corresponding sensation in the visual and motor fields. She had a chance then to discuss each image as it came up and before she graded it. Emphasis was placed upon the comparison between images and sensations, with the result that the observers universally graded themselves lower than if they had not had this preliminary training.

One of the points about the imagery test which makes it hard to deal with is that the one who ranks himself with judgment and discrimination is given a lower grade than one who gives himself a blanket high grade without any variation. The only comprehensive tables of rank with which one can compare the imagery grades of the music students are those of Agnew, which did not give the training and caution about the difference between an image and a sensation which the Evanston test did. The Evanston ranks on imagery do not, therefore, truly represent the standing which the music students should have in an unselected group.

For qualitative analysis of mental processes, however, the imagery tests are invaluable. There are no other measurements which are referred to more often when considering the bearing of one test upon another. The comparative rank which the students gave themselves in the three types of imagery was helpful and enlightening. It is an unsatisfactory test to use in a quantitative way but extremely useful in the analysis of the one whose musical talent is being measured.

member a series of tones by their sound alone better than most people. This correlates well with her rank in auditory imagery. She is average in actually memorizing her musical selections. Memory is a very complex process in all of its associate factors. The reason A is not so superior in the process of memorizing music that she plays and sings is undoubtedly to be found in the slowness of her motor coördination. Her superior auditory learning is probably correlated with the keenness of her ear. Her learning by means of vision is better than average and will help out her auditory learning.

Musical Intellect: In her intelligence quotient, which is 101, A is average (12). She will therefore enter into the intellectual pursuit of music just as the average adult would. This may account for her average rank in ear training into which, as it is taught, the intellectual comprehension enters much more than the sensory impression.

Musical Feeling: A has an extreme sensitiveness to music as heard. Her early desire to hear music is based upon this sensitiveness. She would rather listen to music than play it herself, which is a conspicuous fact in connection with her measurements; for A's music is not a medium for self-expression but rather a purely sensory means of impression. She can hear the music better than she can produce it and early recognized this fact. When she does play she wants to play whatever "people like." She does not feel that she has something which she must play to them. But she is aroused emotionally by the sheer sound of music.

Her aim and ambition is to be a public school music teacher, or, perhaps, a piano teacher. She has no desire to become a concert player and has studied music because of her interest in appreciation, not because of her power to perform it. She has no insistent urge to express herself in music, nor does she feel driven to work out a musical career through her playing.

She is distinctly superior in application and wants to do whatever she undertakes in a thorough and conscientious manner. Superior sensitivity added to slow motor ability and average intelligence are the factors which will probably work together to make A of average ability in her own achievement in music. Her superior power of application and a conscientious desire to do any task well, a pleasing personality and a beautiful speaking voice added to a remarkable appreciation of the aesthetics of music will enable her to succeed as a teacher.

Case B.

Musical History of the Family: B belongs to a family which has been musical on both sides for at least three generations. The ancestors on the mother's side as well as on the father's side had music and musical instruments before any one else in their community. B's father played on the organ before his feet could reach the pedals. Later he sang tenor in oratorio and at Chautauquas. He became an educator and made a special point of developing the music in his school, having, for instance, a brass band among his pupils when he was principal of a school in Chicago. B's mother sang and played a great deal in her youth, and her three sisters are all musical and succeed well in their musical studies. The two older sisters sing, being endowed with rather unusual voices, and they play the piano acceptably.

Personal Musical History: When B was only a year old her mother recorded in a diary that she could hum "America," "Annie Rooney," "Go Tell Aunt Nancy," and "At the Cross." When she was four years old she sang a song alone at a Christmas tree, and when she was five years old her mother recorded: "She cannot let the piano alone," and "she picks out tunes and chords played by her older sister." When she was five years old she began piano lessons which have continued with slight interruptions to the present time.

B has played accompaniments for her father and sisters in Schubert, Schumann, and Mendelssohn, has played in church and Sunday school a great deal, and has done accompanying in public concerts. She has played the alto horn for her father in his brass band, and she has organized an orchestra which performed the incidental music for two college plays. She wrote the class song when graduating from the grammar grade and also when graduating from high school.

Although B has never had any singing lessons she has a voice which is above the average in quality and range, and she has often sung in choruses.

When B was about to graduate from college she decided that she would like a certificate from the music course also. Her instructor informed her that this would be granted on the condition that she would present the proper program. She applied herself to the task memorizing in one term a program of compositions of the virtuoso class. She is now twenty-four years old.

Musical Sensitivity: B's acuity of hearing is average, as is also her sense of pitch. It may be that the latter measurement is cognitive rather than physiological, since it was the result of the first test given to the group and when B was not in the best physical condition. Accepting it as approximately correct, however, we may conclude that her hearing of pitch differences is keen enough to become a good working basis for the enjoyment and reproduction of tone in music.

B's sense of intensity is very keen, which accords well with her ability to play the piano with expression. The extreme sensitiveness to intensity is one of the conspicuous facts about B's sensory capacity and a strength upon which much of her ability rests. It probably compensates for any lack in her sense of pitch and may be the basis for a peculiarly effective kind of appreciation and reproduction of musical tone. Intensity is also "a clear cut test of the intellectual capacity for accuracy in the observation of sound" (7, p. 84).

In the sense of time B is average and therefore reasonably endowed for development in her chosen field of music. Her sense of rhythm is high as shown by her rank in rhythmic and timed action. It is also conspicuous in the serial action tests where she was one of the steady reactors. Her sense of consonance is above average. She has a high rank in the ear training classes and possesses that clearly defined feeling for harmonic values which is essential for artistic performance on the piano and for appreciation of the complicated music of the orchestra. In the light of this high rank in intensity and auditory imagery, we know that B's sense of timbre is above average, and her delight in orchestra music shows that she has a keen recognition of the intensity and volume of tone.

Musical Action: B's records in simple and complex reaction indicate her ability to make motor responses to sound. She is superior both in the ability to respond to a simple stimulus and in the ability to make a choice between two sounds and respond with the appropriate action. Every measurement of motor response indicates that B can act more quickly and intelligently in response to sound than the average person can. She is inferior in her reaction to the complicated auditory stimuli used in this test, and is, therefore, slow in establishing such an auditory-motor combination. Her visual serial action is superior both in time and accuracy. This indicates that she can read the notes of a page of music and make the proper motions at sight of the new combinations of notes with rapidity and facility.

The tests which indicate control of pitch are those of singing key, singing interval, and voice control. Her error in the reproduction of a keynote is .25 v. d., which gives her a very superior rank. In singing intervals we find that she makes an average error of 1.7 v. d., which is very good and speaks well for her fidelity in tonal memory.

The fact that the range and quality of B's voice are good, added to the ability to sing accurately, means that had she so chosen she might have expressed her music quite as satisfactorily by means of her voice as with the piano.

The measurements which show the control of time are those of free action and timed action. B's rank in the former is higher than the average, and in the latter is very superior. Her rank in free action correlates well with that in time sense and is what might be expected; for, as Seashore says, "free action is the motor aspect of which time sense is the sensory or central" (7, p. 62).

B's superior timed action is probably indicative of her superior intellectual capacity and of her training in music. She is able to concentrate her attention upon the outside stimulus and control her responses to it in a very superior manner. Her rank in these simple types of controlled action show that her music will be correct and accurate in tempo and the time elements of her playing will be well marked.

B's rank in rhythmic action is above the average. Rhythmic action differs from timed action in that the stimulus is not objectively set. B's rhythmic action is conspicuously like her free action; in both of them she has about the same rank. It is interesting and important to note that in free action and in rhythmic action, which are B's subjective responses to rhythm, she is average. The same is true of her rank in pitch. Yet in timed action, the response to an outside stimulus, and in singing pitch, also the reproduction of an objective stimulus she is conspicuously superior. These point out the extremely economical use which B makes of all the capacity with which she is endowed.

B's rank in grip is an index of her general bodily strength. She has the physical endurance necessary for the practice and playing involved in the study of any musical instrument. She shows a nervousness in the precision test, however, which gives her a low percentile rank and would seem to indicate that she should not force herself too much in strenuous practice and performance.

Musical Memory and Imagination: B's rank in auditory imagery is above the average. She has the power to image tone and therefore to image a complicated series of tones in a musical composition. If she can imagine the music which she wishes to play—its pitch, its time, its intensity, and its timbre—and can reproduce the effects which she hears in her imagination, she has one of the most important qualifications of a musician. All of her comments on music, the manner in which she plays, her power to imagine the timbre of the various musical instruments, are evidence that her auditory imagery is good. Auditory imagery is also one of the factors in the accuracy of singing intervals, and is probably partly responsible for B's high rank in the three tests for accuracy in singing.

Her motor imagery is superior. This good motor control would also indicate the same degree of motor imagery. Her motor imagery enters into her ability to play accurately and to express the musical ideas which she perceives through her imagination.

B's creative imagination is shown in her early compositions and in her rank in composition classes. Although she has some indication of creative imagination and an inventive mind her interest has not seemed to arouse in her any particular desire to express herself in this way. It is evident that the pleasure which she finds in reproducing the music of others so absorbs her that she is not concerned with developing her own musical ideas. She does over other people's compositions very well but is not self-expressive enough to wish to concentrate on producing that which is original. Yet she has more than the average possibilities on the creative side of music.

B is superior in visual learning; she has superior learning power in response to a visual stimulus. For her musical use this means that she can read the notes of a page of music and make the proper motions at the sight of the notes with rapidity and precision. She is also unusually accurate in her sight playing She learns from the sight of the printed notes, however, less rapidly than from the sound of them.

Her rank in auditory memory is very high. This correlates with her learning power in response to an auditory stimulus and with her rank in all sorts of motor response to tone; namely, accuracy of singing, simple and complex reaction to sound, and with her rank in auditory and motor imagery. All of these measurements indicate what she has shown to be true about her playing, that she has unusual ability to memorize long and involved musical compositions.

Musical Intellect: B's intelligence quotient is 113, which is high. She graduated from college with honors. She is of the intellectual type musically and finds pleasure in the analysis of the form and structure of music. She likes to teach and has been given a class of freshman girls in the conservatory whom she drills in scales and triads. She is very superior both in her ear training and in sight singing classes. Temperamentally she is intellectual and approaches music from this angle.

Musical Feeling: B likes absolute music. She does not need a program of the story of an opera to make her appreciation of the music itself keener. In fact she prefers the music which does not have any such distractions. She prefers symphony orchestra music to any other "because it is a combination of so many delightful tones." She would "rather go to a symphony orchestra concert than to opera." She enjoys thinking about the structure of music but believes that this does not detract from her sensuous enjoyment of it at the same time. B really loves her music and says she would keep on with it no matter how much the tests might go against her. She would like to be a concert pianist or accompanist but has not yet decided definitely what she will do.

With her keen imaginative and intellectual comprehension of music B does not lack the emotional element in her playing; on the contrary she plays with warmth and expression. She has a legitimate ambition to conquer the difficulties of rendering artistically and intelligently the music which appeals to her, and on account of her peculiar balance of sensory and motor capacities is able to realize her own ideal to a great extent.

She is an attractive looking girl, older than most of the students in the conservatory because she completed her college course before finishing her music studies. She is quiet and reserved and of the type to express her emotions freely in her music although she would not do so in ordinary conversation. She is well poised and self-reliant and is cordial and pleasant to meet. She is eager to understand the underlying basis of these tests and is interested in everything that has any bearing on music.

General tendencies of capacities in music students

It was not deemed advisable to present the analysis of the twenty-six cases in detail because there is necessarily much repetition. The two cases here presented give the reader an idea of the manner of analysis which seems to be serviceable when the measurements of any individual are to be used for diagnosis. In the following paragraphs there is a summary of the results of the tests which were given together with a grouping of the students, not only in view of these results, but also according to the achievement of the potential musicians:

In acuity of hearing only two are below average, and these two are above average in the four other sensory tests and memory. In the sense of pitch, the sense of time, and the sense of intensity none are below average. In the sense of consonance one is below average, and she is not below average in the other sensory measurements and memory. Judging from the records of these twenty-six students, no one who is not on the whole average in the ability to hear tones and to discriminate the pitch, the intensity and the time of tones, with the resultant ability to remember tones, ordinarily gets so far in her musical studies as to enter a music school. Those who are below average in their sensory acuteness are weeded out before this stage is reached. The records seem to indicate that such capacity should be above average in at least two or three of these elements in those who desire to make music their profession.

The next group of tests, those of motor ability and power of motor coördination brings out another fact. Here the music students begin to differ from one another. In simple reaction seventeen are average or above and eight are below average. In complex reaction twenty are average or above and five are below, and in motor reliability nineteen are average or above and twelve are below. In auditory serial action nineteen are average or above and seven are below. In visual serial action seventeen are average or above and nine are below. In general, the music students vary in the speed of their actions as a larger normal group would: their music probably takes on the characteristics of the personal equation in each type of action.

There is a striking uniformity in the rhythmic ability of the music students. In free action twenty-one are average or above and four are below. In timed action all are average or above.

In rhythmic action twenty-five are above average and one below. In precision of action in which the ability to perform in rhythm is a factor, twenty-five have a rank average or above and one a rank below. In no case is an individual below average in more than one of the measurements. Ability to perform in time and rhythm seems to be almost as necessary a qualification for a music student as ability to hear tones with keen discrimination.

The measurements of grip vary as they naturally would in a group which is not chosen on the basis of physical vitality. Twenty-five are average or above in this test and one is below.

Another group of tests in which the music students are conspicuously uniform is that of accuracy of singing. In singing the key-note all but two are average or above, and in singing the interval and in control of voice the same is true. In the two latter tests training is a large factor, and training the conservatory students all get whether they have voices or not.

In auditory imagery twenty graded themselves average or above. In intelligence all are again average or above, being in large part a selected group.

The general conclusions about the various groups of tests may be summarized in this way:

There are certain measurements in which the music students as a selected group are of rather uniformly high rank. These are: (1) the factors of musical sensitivity and tonal memory; (2) ability to play in accurately marked time; (3) accuracy of pitch singing; and (4) intelligence.

There are other measurements in which they differ; namely, (1) in the factors of musical action, some being quick and accurate, some being slow and accurate, some being quick and inaccurate, and some being slow and inaccurate; (2) in the types of their imagery, and therefore in the manner in which they approach, memorize and learn music.

The relative proportions of these various factors may be assembled in an infinite number of ways in the different individuals, each of whom has some characteristic adjustment in which every other one is lacking. As Donaldson says: "On the balance of these component parts depends the somewhat subtle character called temperament, which, though illusive, has a real existence and an importance hard to estimate. Temperament is the expression of these relations and one of the nice problems the clinician has to face" (3, p. 316). Each individual should be studied as an individual and his strength and weakness discovered. These then become his known capital and he can proceed with the assurance of one who knows what is behind him.

Brief mention of individual cases

Turning now to a reconsideration of the typical results: These music students seem to be divided into four groups on the basis of their total scores in the measurements. The first group, which we shall call Group I, is made up of those who are high in all of the measurements. They give a comparatively simple answer to the question as to whether those who are superior in sensory capacity, motor capacity, voice, imagery, learning and intelligence, are also superior in achievement; for the answer in each case is, undoubtedly, affirmative. The eight who compose this group on the whole have the best record of achievement among those who were tested.

Five of Group I are exceptionally good pianists. The first of this group has, however, even more promise of success as a singer than as a pianist. She has the most conspicuously superior talent chart of all and is a composer and organist as well as a pianist and a singer. The second is also superior in achievement as a singer and as a pianist, even now in her student days, and has been given student teaching in the conservatory. The next two might do something quite creditable with their voices so far as innate capacity is concerned, but they have not as yet specialized in voice. The fifth began her lessons comparatively late and will not be able to do much with the piano. She gives promise of unusual success as a singer. The sixth is a good all-round musician, a good pianist and endowed with an unusual contralto voice. She prefers singing to any other method of musical expression for herself. The seventh of this group needs a somewhat detailed description. As a child she acquired a particularly sturdy complex against piano playing owing to the stupid and monotonous drudgery connected with her piano lessons. She had studied with a teacher who kept her at long drawn-out tasks which resulted in the above mentioned aversion to the piano. This aversion she still feels and does not care to make that instrument the medium of her musical expression. She has only the average range and quality of voice and probably will have only an average grade of achievement in singing. But she loves dancing and desires above all things to express herself in that. She came to the conservatory with dancing particularly in mind but was forced to give it up, at least temporarily, on account of an operation and is devoting the period of waiting to the study of public school music.

Group II is made up of those who are high in the measurements of all the factors, except those concerned with motor capacity, where they are average. These cannot be grouped by their likenesses but must be described individually by their differences. Three of them have lovely voices and give promise of becoming unusual singers. Three more are excellent performers on the piano; one of them being considered among the best in the music school. The other two show a lack of poise and self-control which may be indicated by the motor tests. The seventh plays the piano well but does not care to be a performer. She is studying to be a public school music teacher.

Average motor capacity, then, in conjunction with high sensory keenness, seems to admit of high achievement, although not invariably as in Group I, where the motor capacity is also high.

Group III comprises those students who are high in sensory capacity but low in some respects in the motor tests. It may be noted here that the motor tests themselves are to be diagnostic only in connection with the description of the cases. "Temperament," "lack of self-confidence," and "over self-confidence," seem to enter into the final achievement as much as innate capacity, as shown by the measurements. The first of this group is so far below the standard required in this music school that she has been advised to discontinue her musical studies. The second girl in this group can also be explained only by a study of other elements than the actual results of the tests. She is overweeningly ambitious, but at the same time hardworking and conscientious. Her teachers say that she shows no signs of becoming the expert performer that from her ambition and industry she very evidently confidently expects to be. Her singing voice is only ordinary although she expects to develop into a concert singer. She appears to be quite unconscious of the value of the experience of those around her. She cannot take advice. Her innate capacity, except in the range and quality of her voice, seems to be of sufficient merit, but the fact remains that she is accomplishing very little. The third member of this group is the one described in full as A. Her superior sensory capacity and rather inferior motor capacity work out quite logically in explaining her appreciation of the beauty of music without producing within her any overwhelming desire to be an expert performer. The fourth member of Group III has a very beautiful singing voice, and with a very few piano lessons has learned to play her own accompaniments. She is considered one of the successes of the music school. She is a peculiarly well balanced young woman and able to live up to the full possibilities of her inborn powers. The fifth in the group cannot sing at all but is becoming a good piano player.

Group IV embraces those who are well above the average in their sensory measurements, and who are on the whole average in their motor measurements. Three of this group are good singers. The first also gave promise at one time of being a good violinist, but was interrupted in her study of that instrument. She has serious trouble with her eyes which has continued from childhood. Indeed, as a child it had a pernicious influence upon her, making her feel a quite unwarranted sense of inferiority. She is unable even now to do the work of the music school, such as the writing of music scores, which depends upon the use of the eyes. But an unusually lovely voice which she is learning to use successfully is restoring her self-confidence, and she will undoubtedly do excellent musical work. The second is also endowed with a voice of superior range and quality; she has grown up in a musical environment and is doing excellent singing. The third is gifted with a beautiful singing voice and is only impeded in her career by a frail physique.

The fourth in this group is developing into a good pianist, but the character of her playing will be limited by the structure of her hand which is small and delicate. She has the characteristic, in common with the fifth, of being somewhat lacking in determination and energy. Both of them may be acceptable players but their temperaments will not lead them on to great musical triumphs. The sixth, with no conspicuous inferiority in sensory or motor capacity, will probably never achieve very great success in music, because she is not single-minded in her wish to succeed. She comes to the music school because she is sent there by her parents and is not sufficiently motivated to make her study of music count toward definite accomplishment. The seventh case in this group deserves separate mention. Like the others the psychological measurements find her excellent in sensory capacity and average in motor capacity. But she is not even so good a performer as most of the others. There is no reason she could not learn to perform very creditably on some instrument except the fact that she is so interested in composing that she uses her powers of performance merely as an aid in composition and not as an end in itself. She seems to possess the musical creative impulse, and, so far as her comparatively short musical studies have led her, stands out as a possible creative musician.

From the foregoing study, then, we would seem justified in saying that those who are superior in every way in their innate musical capacities, as shown by the tests, are superior in their achievement, while those who are superior or excellent in sensory capacity but average in motor capacity may become superior performers if all the conditions of environment, training, and the adjustment of physical and mental equipment are favorable. If, on the other hand, their environmental factors are unfavorable their native powers may be so inhibited as to preclude the possibility of their becoming even passable performers.

It is unfortunate, from the standpoint of research, that in this music school there was no opportunity to compare the measurements of those who fail in trying to learn music. There is undoubtedly a weeding out process before the music school is reached, and we shall rarely find there any who will be very low in all the sensory and motor measurements.

In this connection it may be well to mention briefly here the results of a later study of a selected group of students in a Normal School. Of twenty students reported as unable to learn the required music only two were found to be even average in sensory capacity. None but the sensory measurements were made but observation of the singing of these two revealed the fact that there was distinct motor inferiority which made them unable to reproduce the sounds which they heard. The diagnosis of the other eighteen was extremely simple. They were distinctly inferior in sensory capacity and the resultant inferiority in achievement logically ensued.

Some practical suggestions

There are two ways at least in which these tests may be used practically in a music school. First, they give an analysis of the capacities upon which the individual student must rely, and also an objective measurement to the teacher which he can compare with the actual achievement of the student. Thus, if a student is superior in all his capacities according to the tests and is not living up to his possibilities, this fact can be presented to both the student himself and to his teacher in a concrete and specific form. If a student is of the average in his innate capacities as shown by the tests, neither he nor his teacher has the right to expect the same quality or quantity of performance to which the superior student should attain.

The second and perhaps the most important way in which the results of these measurements may be used is in finding out the strengths and weaknesses of individual students. Among those who are neither conspicuously superior nor inferior are many who are not working in the way to attain the best results. Different arrangements of sensory and motor capacities; various types of imagery and intelligence demand their appropriate treatment. The modern music teacher must consider his pupil as an individual, with all his capacities individual; not just a capacity for music, but *capacities* to be analyzed as such and treated according to their need. For such an analysis and diagnosis, these psychological measurements are especially designed. They reveal strength or disability; they show where training may profitably be undertaken or when time and strength may be used to greater advantage in other pursuits. Hence they become an important aid to instruction. We would not think of training a Clydesdale for the race track; why attempt the impossibility of making a musician out of one who is non-musical?

It would seem, therefore, that it might be an economy if a psychologist capable of making such analyses were attached to every school of music. He would be not only of great assistance to the students who have already begun their study of music, and to the teachers who have them in charge; but he would be of even greater service to the young children who appear as prospective pupils. A knowledge of the possibilities of each individual before the actual study of music is undertaken would enable the teachers to stimulate the genius of the talented child to his full possibilities; to help the average child according to his known strength or weakness, and to reject those who are so inferior that time and effort expended in their training for a musical career is a crime. The encouragement of the superior and average by intelligent analysis would more than compensate in increased patronage for the loss of a few who should be discouraged. The wasteful, haphazard system of teaching music which has existed hitherto, even among conscientious teachers, is possibly no worse than in other departments of education, but it should be eliminated as far as possible in order to conserve musical talent. The resulting increase in achievement would enrich the profession of music incalculably, for "We have countless wonderful capacities lying latent and unrecognized as far as conscious use is concerned. The apparent squandering of sensory capacities (alone) may well be compared to the great waste in the struggle for existence by various forms of prolific extravagance in reproduction. We are richly endowed with capacities of which we employ relatively few, and these only in an inadequate way" (8, p. 157).

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THE INHERITANCE OF SPECIFIC MUSICAL CAPACITIES

by

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Description of material; method of investigation; analyzed rating of supplementary data (musical environment, education and training, activity, appreciation, memory and imagination, emotional reaction to music, rôle of music in daily life, creative ability in music, higher education independent of music); records: Kappa, Rho, Alpha, Lambda, Gamma and Epsilon groups (explanation and legend of talent pedigree charts, rating in musical activity and talent charts, explanation of tables, family musical history); types of mating and progeny: based upon ancestral musical items; discussion of data on the inheritance of musical capacities (family distribution of capacities, method of inheritance, presence or absence of determiner); problem of different age groups; relation of musical capacities to supplementary data; summary of supplementary factors for the two contrasted groups of talent profiles; comparison of highest five per cent and lowest five per cent; general summary; references.

The experimental investigation of musical inheritance with members of musical families was initiated in 1920 through the generous coöperation of men[1] prominent in the fields of psychology, genetics, and music. The immediate purpose of this investigation is an attempt by means of quantitative methods to secure information regarding the inheritance of certain musical capacities. A more remote purpose is the study of the significance of such specific measures in interpreting the inheritance of the manifold musical capacities which comprise musical talent. A necessary prerequisite to this procedure is the development

[1] Dr. C. E. Seashore, Head of the Department of Philosophy and Psychology, State University of Iowa, made the scientific approach to this problem possible by many years of directed research in developing and standardizing measurements of basic musical capacities. Dr. C. B. Davenport, Director of the Department of Genetics, Carnegie Institution of Washington, was personally instrumental in effecting this study of inheritance. Their constructive suggestions and sustained interest throughout the study were most helpful.

of the scientific psychology of music in which musical talent can be analyzed into basic musical capacities that may be isolated and reliably measured in persons who are musical or unmusical, young or old, trained or untrained.

This report of procedure of the results so far obtained serves a three-fold purpose: to record the method of procedure, both general and specific; to classify the data in preparation for further investigation; and to formulate tentative conclusions as to the probable type of inheritance in the light of these data.

It was deemed expedient to begin this work with recognized musical families[2] in the East and Middle West; therefore the writer was given several months leave of absence from the State University of Iowa. The necessary expenses of field work were met by an appropriation granted by the Carnegie Institution of Washington, through the Department of Genetics, Cold Spring Harbor, Long Island, New York.

Description of material

Considering the time allotted for field work, the number and kind of available measures of musical talent, and the various possibilities of selecting observers (7, p. 597), there were several plans feasible for this preliminary investigation. In the plan followed, four measures of musical capacities, the sense of pitch, the sense of intensity, the sense of time, and tonal memory, were given to members of families in which one member was known to be conspicuously talented in music. These four capacities were selected for a study of the inheritance of certain musical traits because extensive experimentation has revealed their apparent basic nature and has shown them to be little affected by practice, age, musical training, sex, or general intelligence. The measures were supplemented by a special interrogation dealing with individual case histories, individual musical experiences, family musical history, and a short association test.

The measurements of intensity discrimination, time discrim-

[2] In behalf of those interested in the procedure of this study I sincerely thank the musicians and their relatives for their willing and faithful cooperation.

ination, and tonal memory were given by phonographic records[3] on which stimuli from the standard laboratory apparatus have been recorded by Professor C. E. Seashore.

For the measurement of the sense of pitch in terms of pitch discrimination, the standard pitch discrimination forks with resonators were used in place of the phonograph record, first, because they are better adapted for very fine measurements, and second, in order to introduce variety in the procedure (9, p. 26).

Pitch discrimination (9) is measured by pitch intervals ranging from 30 d. v. to ¼ d. v. in a tonal region of 435 d. v. The observer discriminates between two tones differing in pitch, the second tone presented being higher or lower than the first. For the purpose of intensive work the individual method of constant stimuli was used in preference to the group method. The threshold values were computed from conversion tables (4).

Intensity, time, and memory were studied by means of the serial stimulus method: *i.e.,* a series of fifty or one hundred stimulus differences was given and a record was made on the basis of per cent. right for the series (6, p. 79, 103, 236).

Intensity discrimination (6, p. 79) is a measure of the capacity for discriminating differences in intensity or loudness. This measure contains five graduated steps, the first easily perceptible, the last very difficult to perceive.

The measurement of time discrimination (6, p. 103) refers to an individual's capacity for discriminating between two time intervals, the second one presented being longer or shorter than the first. The stimuli cover a range of five steps, varying from an easily perceptible difference of .20 second to a difference of .02 second. The series of stimuli contain twenty trials for each step. Such a measure of an individual's capacity for discriminating time intervals is not a measure of rhythmic perception but a measure of one of the basic constituents of rhythm. It gives one partial knowledge of the sensory aspects of rhythm, the receiving of an elementary impression of time which depends upon more than the functioning of a sensitive ear.

[3] *Seashore's Measures of Musical Talent*: A and B 7537, Sense of Intensity; A and B 7538, Sense of Time; A and B 7540, Tonal Memory. The Columbia Graphophone Company, (10) New York.

The test of tonal memory (6, p. 236) is a measure of immediate memory for a span of tones. It consists of five steps gradually increasing in difficulty, each step containing a certain number of successively presented tones followed by a second span of the same tones with the exception of one tone which is changed in pitch. The spans increase gradually in presentation from two tones to six tones. The observer identifies the changed tone by indicating its number in the group. This measure of the capacity for immediate memory is servicable only as one of the many possibilities of measuring the different aspects of musical memory.

Norms. The answers to all the trials of a measure are recorded for each observer on prepared record blanks. From these answers the percentage of right judgments is found in order to evaluate the per cent. right in terms of percentile ranks[4] based on the results obtained from a large unselected group.

Method of investigation

In the fall of 1919, Dr. C. B. Davenport sent letters to a number of American musicians asking their coöperation in a proposed family study of musical inheritance in which the Seashore Measures of Musical Talent would be used, also inquiring as to the number of living sibs (brothers and sisters) and the size of the family. These musicians, favorably located, were chosen for the reason that they were American musicians who had attained an established reputation in music.

Selection of families. Cordial responses were received from many musicians. In selecting those from whom a family study could be developed we chose musicians who were available for an interview during the months reserved for their section of the country and who had families the members of which were significant in number and available for appointments.

Scope of investigation. The unrelated musicians selected according to the factors mentioned above form the centre of each

[4] The percentile rank tables used for intensity, time, and memory are found in the Manual (10). The percentile rank for pitch thresholds with tuning forks is not published.

family group. In so far as possible a family study includes all members of the so-called restricted family (3, p. 6). As a result over five hundred individuals are charted in six family groups. Of these groups eighty-five persons were interviewed and given the measures of musical capacities. The persons interviewed range in age from eight years to eighty years. The propositi[5] range in age from forty-five years to sixty-five years; consequently their parents are deceased or very old. A three generation study was possible in five of the six family groups.

Procedure. The individual interviews were easily adapted to one or to several periods of time. Under most favorable conditions the total individual time requisite was two hours. In some cases several members of a family could be assembled for the group measurements. The interviews occurred in various places,—the studio, the home, the college, the office, or the rooming place. The essential requirement was a reasonably quiet place, comparatively free from interruptions.

The most advantageous order of presenting the material proved to be, (1) the measure of pitch discrimination with the tuning forks, (2) the free association test, (3) the three measures on the phonographic discs, the sense of intensity, the sense of time, tonal memory; (4) the interrogation.

Objective and subjective variables. Field work of this nature involves various conditions which may exert favorable or unfavorable objective and subjective influence upon the individual results. Some of these influencing variables were the place, time and length of the appointments, the apparatus used, the personality of the experimenter, the number and effect of interruptions, the grasping of directions by the observer, his mental poise, interest and concentration.

Analyzed rating of supplementary data

That part of the supplementary data which covers the musical information is divided into the five sections of environment, education and training, activity, appreciation, and memory and imagination. In each of these sections minor statements and

[5] The musicians from whom each family study progressed.

questions subordinate to the general topic were submitted verbally to each person. In brief they are as follows:

Musical environment

Opportunities for hearing music in parental home; members of family who play and sing; musical instruments in the home.

Opportunities for hearing music in the community; to what extent were these opportunities utilized.

Individual effort exerted to gain or avoid a musical environment.

Musical encouragement in the home.

Musical education and training

Study in voice, with an instrument, in composition, harmony, theory, orchestration, etc; time spent with each (approximate number of years); time of life in which study occurred.

Musical activity

Type of musical activity; instrumentalist, vocalist, composer, conductor, writer, lecturer.

Public appearances in singing or playing.

Tonal range in singing.

Natural ability to carry a tune, to improvise, to play by ear, to transpose, to read at sight.

Musical appreciation

Earliest interest in music.

Kinds of music liked and disliked.

Kinds and degree of feeling aroused by music; what type of music arouses this feeling.

Rôle of music in daily thought.

Desire to have studied or heard music.

Musical memory and imagination

Facility of memorizing; aids: visual, auditory, tactual, technical knowledge.

Music recalled by ear, sight, or movement.

Type of melodies present in mind, occasionally or continually, during work, rest, or play.

Creative efforts.

One question often stimulated a response which covered many of the items listed without further inquiry. In all but a few cases restraint was evidenced on the part of the person responding.

For the purpose of presenting and correlating this musical information with the results of the musical measurements an attempt was made to classify and rate such of the material as seemed adequate.

Since the scope of this investigation includes one well recognized musician in each family group a wide variation exists, from those who have made signal achievement in music to those who are not at all musically inclined. This variation, inclusive as it is of two extremes, forms the basis of classification into three groups: the A group, considered high; the C group, average; and the E group, low. Later inclusion of more cases will justify a more detailed classification and perhaps a more definite basis of classification. It has been a conscious aim in introducing this classification to prepare the way for further study so that B and D groups may be inserted.

For each item rated, examples of class A, C, and E will be given on the following pages. These examples are specific illustrations of information obtained from those interviewed.

Musical environment during youth in the home

A—Musical artists heard frequently in the home during concert tours.
One or both parents professional musicians and expressing their art in the home.
Parents' studio in the home.

C—Several members of the family studying music.
Family singing or playing daily.

E—Hymns sung at morning prayer.
Self practising.
One parent playing or singing occasionally.
No music heard at all.

Musical environment during youth in the community

A—Heard opera and concerts by vocal or instrumental artists, either solo or ensemble.
Attended city music festivals.

B—Heard one or two musical artists or symphony concerts occasionally.
Often heard good church organist.

E—Heard only church and Sunday-school music in small village.
No concerts heard.

Musical environment in the community during adult life

A—Regular attendant of winter concerts and opera in New York City, Boston, and Chicago.

C—Attended college concerts regularly.
Went to the city occasionally for a concert.

E—Country church music.
Singing school.

Few musical programs heard.
No concerts attended.

Musical education and training

A—Major in music during a university or college course accompanied and followed by extensive private study.
One or more years' study abroad.

C—Music courses in college or private lessons in musical theory, in addition to several years of study in voice or instrument or both earlier in life.

E—Three or four years of study on an instrument early in life.
Occasional lessons on one or more instruments.
No musical education or training.

Musical activity

A—Studio or concert artists.
Musical educators and writers.
Composers of merit.
Recognized professional teachers.

C—Appeared in public recitals, amateur performances, choruses, choirs.
Few compositions in manuscript only.

E—Played hymns.
Sang few times in glee clubs.
No public appearances.

Emotional reaction to music

A—Repeated experiences of emotional states, aroused by musical stimulation, expressed in the form of exhaustion, sobbing, exhilaration, transferred into another world, conscious outgo of emotional power.

C—Occasional experiences of forgetting self, feeling of inspiration, cold chills or thrills.

E—No conscious reaction experienced.
Vague feeling of unhappiness or joy.

Rôle of music in daily life

A—Private teacher of voice or instrument.
Music a part of daily mental diet.
Great source of courage, a spiritual tonic, a daily necessity.

C—Several hours each day of practice.

E—No daily thought given to music.
No music heard.

Creative ability in music

A—Composer of songs, choruses, concertos, symphonies.

C—Improviser.
Manuscript compositions.
Writes music for operettas.

E—No creative power.

Higher education independent of music

A—Graduate degrees or advanced professional degrees.
Completion of a four-year university or college course with a degree.
C—Less than four years' college study.
E—No college or university study.
Incomplete high school education.

The number of cases occurring in each of the three groups for each topic above is recorded in the tables found in the section showing the relationships between musical capacities and supplementary data.

Records

The records for each family group consist of four parts. (1) the talent pedigree charts of musical capacities, (2) tabulation of individual ratings in musical activity and talent profile classification, (3) tables of classified musical information and measures of musical capacities, (4) family musical history.

Explanation and legend of talent pedigree charts. In each of the talent pedigree charts the Roman numerals at the left indicate the generation number, the Arabic numerals give the individual number. These numbers are taken from the original pedigree charts.[6] The squares indicate males; the circles, females. A connecting horizontal line from a square to a circle shows a mating. Any continuous horizontal line with vertical drops and usually suspended from a mating in the generation above comprises a sibship. Greek letter names were arbitarily assigned to each of the six family groups. In order to represent on one chart the results of the musical measurements for each individual, a small diagrammatic talent chart is suspended from the squares and circles. Its scope from left to right indicates the percentile rank ranging in ten divisions from 1 to 100. The four horizontal divisions provide for the recording of the rank for each measurement of musical capacity. The pitch rank is designated in the upper section, the intensity rank in the second,

[6] The original pedigree charts, filed in the Eugenics Record Office, include relatives, about whom musical information was obtained, in addition to those interviewed. The talent pedigree charts include only those to whom the measurements of musical talent were given.

the time rank in the third, and the memory rank in the lower section. Comparison of parents and children may be made directly from any measurement by observing the percentile rank for each capacity which is indicated by the heavy black vertical line. Each percentile rank line is interpreted by its distance from the left side of the talent chart in terms of the scale given on the next following page. Each talent chart contains four such vertical lines connected so as to represent a talent profile. The dotted black vertical line means that no rank was obtained in the measurement. An incomplete pattern is due to the omission of some of the measurements.

Rating in musical activity and talent charts. For the purpose of relating the four capacities as a whole to various phases of the supplementary data, each talent profile has been classified as superior, excellent, average, or poor. This classification was made by personal judgment based on a normal distribution of approximately one thousand talent charts of an unselected group (8). Immediately following each talent pedigree chart the rating in musical activity and the talent profile classification for each individual are presented for the purpose of direct comparison between these two factors.

Explanation of tables. The data in each table consist of classified information concerning the persons interviewed. In column 1, individual numbers are preceded by the generation number and group letter; in column 2, M indicates male, F, female; in column 3, the appropriate age in years is given; columns 4, 5, 6, 7, contain results of the four musical measurements; the sense of pitch, the sense of intensity, the sense of time, and tonal memory respectively in terms of the scale, very superior (V. S. 98-100), superior (Sup. 90-97), excellent (Exc. 70-89), high average (H.A. 60-69), average (Ave. 40-59), low average (L.A. 30-39), poor (P. 10-29), very poor (V.P. 1-9). The letters N.R. mean no record; two dashes —— mean no rank.[7] The ratings in columns 8 to 16 are given in terms of A, consid-

[7] "No record" means that the individual did not take the measurement. "No rank" means that the individual tried to take the measurement but failed to make a score.

ered high (A,* very high); C, average; and E, low. Columns 8, 9, 10, indicate the ratings for musical environment during youth in the home and community, and during adult life in the community; column 11, ratings for musical education; column 12, ratings of musical activity; column 13, ratings for creative ability in music; column 14, ratings for emotional reaction to musical stimulation; column 15, ratings for the role of music in daily life; column 16, ratings of general education. In blank spaces where no ratings occur the individuals were too young for classification.

Family musical history. This section includes brief statements made by the observers as to musical expression and interest evinced by members of their lineage. Many of the statements are recorded verbatim although not indicated as quotations.

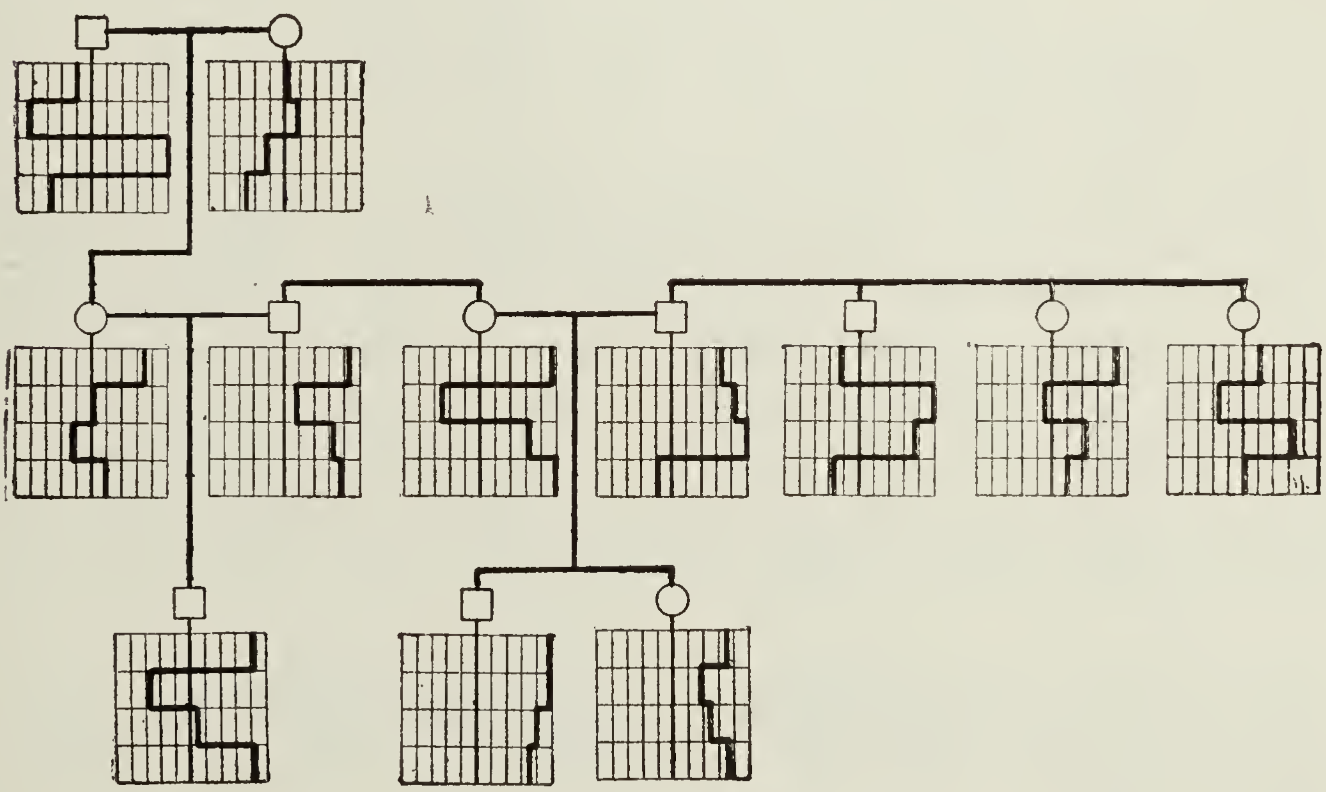

FIG. 1. Talent Pedigree Chart: Kappa Group.
Reference numbers from the left to right, for the first row, III 4, 3; for the second row, IV 2, 3, 6, 7, 9, 11, 12; for the third row, V 1, 5, 4.
Age range—67 years to 8 years.

Classification of musical activity:
Group A—IV 3; group C—III 3; IV 2; group E—III 4; IV 6, 7, 9 11, 12; too young to classify—V 1, 5, 4.

Classification of talent profiles:
Superior—IV 7, V 5; Excellent—IV 3, 6, 9, 11; V 1, 4; Average—III 4, 3; IV 2, 12; Poor—None.

General comment:

III 4 and 3 (both average profiles) have one child with an average profile; IV 2 and 3 (average and excellent profiles) have one child with excellent profile; IV 6 and 7 (excellent and superior profiles) have two children with excellent and superior profiles.

Table I. *Musical data classified: Kappa group*

INDV. REF.		SEX	AGE	MUSICAL CAPACITIES PITCH	INT.	TIME	MEMORY	ENVIRONMENT YOUTH HOME	COM.	AD. COM.	MUSICAL RATINGS EDUC.	ACT.	CREA. ABIL.	EMO. REAC.	DAILY ROLE	GEN. EDUC.
K IV	3	M	51	Sup.	Ave.	Exc.	Exc.	A*	A	A	A*	A*	E	A	A	C
K IV	2	F	38	Exc.	Ave.	L.A.	H.A.	C	C	A	C	C	E	C	E	C
K V	1	M	8	Sup.	Poor	Ave.	Sup.	E								
K III	4	M	67	Ave.	V.P.	V.S.	Poor	C	C	A	E	E	E	E	E	E
K III	3	F	55	Ave.	Ave.	L.A.	Poor	E	A	A	C	C	E	E	C	E
K IV	7	M	50	Exc.	Sup.	V.S.	Ave.	E	E	C	E	E	E	C	E	A*
K IV	6	F	49	V.S.	Poor	Exc.	V.S.	A	A	A	C	E	E	A	C	E
K V	5	M	14	V.S.	V.S.	Sup.	Exc.	C								
K V	4	F	9	Sup.	H.A.	Exc.	Exc.	C								
K IV	9	M	53	L.A.	V.S.	Exc.	L.A.	E	E	C	E	E	E	A	E	A
K IV	11	F	48	Sup.	Ave.	Exc.	H.A.	E	E	E	E	E	E	C	E	A*
K IV	12	F	44	H.A.	L.A.	Exc.	Ave.	E	E	E	E	E	E	C	E	E

Family Musical History, Kappa Group

K IV 2, female, Table 1, plays violin, carries a tune easily.

Sib: Brother studied the cornet.

Maternal side: Mother, III 3, Table 1, plays piano, carries tune easily. Mother's sister studied violin abroad, a professional violinist. Mother's brother picked up tunes quickly on almost any instrument. Mother's father, a carpenter. Mother's mother not enthusiastic about music, played piano very little, her family not musical. Mother's mother's brother, offended at music. Mother's mother's father played cello in church.

Paternal side: Father, III 4, Table 1, whistled melodies. Father's sister studied piano with recognized musician in the East. Father's mother, an amateur pianist. Father's mother's brother played the flute, promoter of musical concerts. Father's father enjoyed music.

K IV 3, male, Table I, voice teacher, plays violin, operatic singer.

Sibs: Brother, deceased, played the cello, had best singing voice (baritone) in the family. Sister, IV 6, Table I, plays piano, does not sing since voice was strained.

Maternal side: Mother a "crack soprano" of New England church singing. During senility she retained as lovely a voice as ever.

Paternal side: Father, an organist, educator, composer of national repute. Father's brother, died in infancy. Father's mother, read poetry constantly to her son. Father's father, not a musician, knew only two tunes, sent son abroad for extensive study in music after talent was evident.

K IV 7, male, Table I, does not play or sing, cannot whistle a tune after hearing it.

Sibs: IV 9, could carry a tune, does not play; IV 11, not able to carry a tune, no playing; IV 12, can carry a tune, no playing. Table I.

Maternal side: Mother not particularly interested in music. Family not musical. Of eleven sibs one sister sang a little but not a lover of music.

Paternal side: Father whistled and sang occasionally, not an educated musician, but passionate lover of music, attended opera night after night, an excellent draftsman. Father's sibs, fourteen in number, one brother played violin, had an untrained singing voice; one brother fond of music, chairman of a church musical committee, attended the rendition of "The Messiah" annually for many years.

Table II. *Musical data classified: Rho group*

			MUSICAL CAPACITIES				MUSICAL RATINGS									
							ENVIRONMENT									
INDV.							YOUTH		AD.			CREA.	EMO.	DAILY	GEN.
REF.	SEX	AGE	PITCH	INT.	TIME	MEMORY	HOME	COM.	COM.	EDUC.	ACT.	ABIL.	REAC.	ROLE	EDUC.
R IV 12	M	55	V.S.	Sup.	Sup.	V.S.	C	C	A	A	A*	A	A	A	A
R IV 13	F	53	V.S.	H.A.	L.A.	Ave.	E	E	C	E	E	E	C	E	A
R V 11	F	24	V.S.	V.S.	V.S.	V.S.	C	A	A	A	C	E	E	E	A
R V 12	F	18	Exc.	Ave.	Poor	Sup.	C	C	C						
R V 13	M	16	V.S.	Exc.	Exc.	V.S.	A	C	C						
R III 24	F	80	Poor	Poor	V.P.	——	E	E	E	E	E	E	E	E	A
R IV 14	F	49	Poor	L.A.	Poor	V.P.	E	E	C	E	E	E	E	E	A
R IV 15	F	40	L.A.	Ave.	V.P.	——	C	E	C	E	E	E	E	E	E
R IV 22	F	59	L.A.	Sup.	H.A.	V.S.	C	C	E	C	A	E	A	C	A
R V 15	F	25	V.S.	V.S.	Sup.	V.S.	A	C	C	C	C	E	A	N.R.	E
R V 14	M	18	V.S.	Ave.	L.A.	Sup.	E	E	C						
R V 16	M	30	V.S.	Poor	V.P.	Sup.	C	E	C	E	E	E	E	C	C
R V 17	F	21	V.S.	Sup.	Sup.	Sup.	C	C	C	E	C	C	C	N.R.	E
R IV 11	M	65	V.S.	Exc.	V.S.	V.S.	E	E	C	C	A	A	A	A	A*
R IV 10	F	62	L.A.	Exc.	Sup.	V.S.	A*	A	A	C	C	C	A	A	C
R V 4	M	34	V.S.	N.R.	N.R.	N.R.	A	C	C	A*	C	E	N.R.	N.R.	C
R V 6	F	28	V.S.	Exc.	V.S.	V.S.	A	C	C	A	C	E	C	A	A*
R V 7	M	37	V.S.	N.R.	N.R.	N.R.	A	C	C	A	A	C	N.R.	A	A*
R V 5	M	26	V.S.	V.S.	V.S.	V.S.	A	C	C	C	C	C	E	C	A
R V 3	F	28	V.S.	N.R.	N.R.	N.R.	E	E	C	E	C	E	C	C	E
R IV 9	F	52	Sup.	Exc.	Exc.	V.S.	A	A	A	C	E	E	A	A	A

Classification of musical activity:

Group A—IV 12, 11, 22; V 7; group C—IV 10, V 11, 5, 6, 4, 3, 15, 17; group E—III 24; IV 14, 15, 13, 9; V 16; too young to classify, V 12, 13, 14.

Classification of talent profiles:

Superior—IV 12, 9, 10, 11; V 11, 13, 5, 6, 15, 17; Excellent—IV 22; V 12, 14, 16; Average—IV 13; Poor—III 24; IV 14, 15.

General comment:

III 24 (poor profile, whose consort was not musical, has three children, two with poor profiles and one with average profile; IV 13 and 12 (average and superior charts) have three children, two with superior profiles and one with an excellent profile; IV 10 and 11 (both superior profiles) have four children, two with superior profiles and two with incomplete profiles; IV 22 (excellent profile), consort not measured, has two children, one with an excellent profile and one with superior profile.

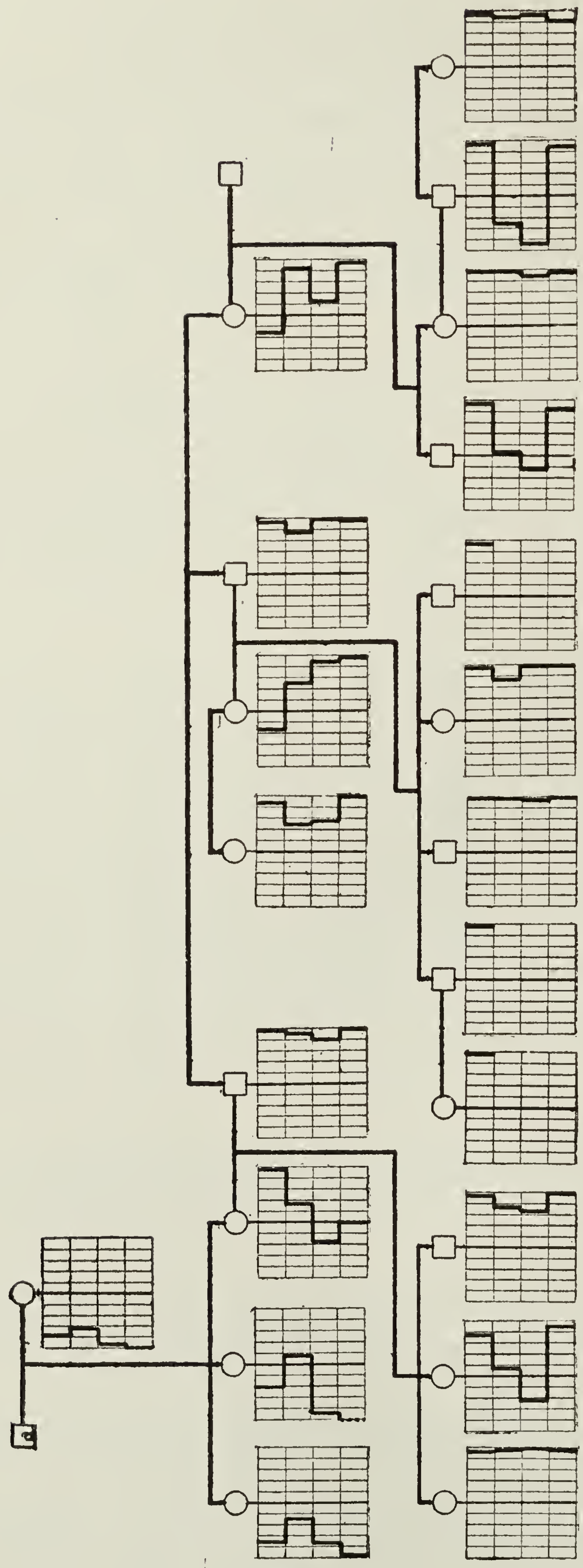

Fig. 2. Talent Pedigree Chart: Rho Group.

Reference numbers from left to right, for the first row, III 25 (deceased), 24; for the second row, IV 14, 15, 13, 12, 9, 10, 11, 22, 23 (did not take the tests); for the third row, V 11, 12, 13, 3, 7, 5, 6, 4, 14, 15, 16, 17. Illness prevented V 3, 7, and 4, from completing the tests.

Age range, 80 years to 16 years.

Family Musical History: Rho group

R V 11, female, Table II, teacher of violin and voice, sings contralto, plays organ and violin.

Sibs: V 12, Table II, sings soprano, plays piano; V 13, Table II plays piano at home, can carry a tune easily.

Maternal side: Mother IV 13, Table II, plays piano, can sing. Mother's five sisters and brothers sang a little in the home only. Mother's father, a minister, unmusical, no musical training but ambitious for his children to study music if possible. None of his family were musical. Mother's father's mother possessed a great longing to express herself through painting. Mother's mother is III 24 in Table II, her two brothers sang in the home, one received pleasure from music; of four half brothers and sisters, one taught singing school in two counties. Mother's mother's mother painted with water colors. Mother's mother's father sang bass occasionally, no music in his parents' home.

Paternal side: Father, IV 12, Table II, college teacher of music, church organist, second bass in quartettes and glee clubs, conducted orchestras, glee clubs, and choirs. One brother, IV 11, Table II, a clergyman, sings baritone, plays organ. One sister, IV 22, Table II, teacher of voice and piano, sings contralto, choral director. Father's mother possessed a peculiarly beautiful soprano voice, remarkable singing range of easily three octaves, played church organ, received considerable musical training, a very cultured woman. Father's mother's brother played the cello, considered an excellent tenor. Father's mother's mother, a leading soprano in village church choir, her family has the reputation of being musical. Father's mother's father sang bass in country church choir, was very fond of music. Father's father a city missionary, sang but did not play; wrote words for church hymns, taught music school. No musical items reported for father's father's three brothers, two sisters, and parents.

R V 4, male, Table II, sings tenor, plays piano, active in musical organizations.

Sibs: V 5, teacher of piano, plays college organ, sings first bass; V 6, sings soprano, plays piano, instructor in music department; V 7, sings first bass, organist, choir master, director of music in city schools; Table II, two sisters deceased.

Maternal side: Mother IV 10, Table II, sings alto, plays piano. Mother's sister, IV 9, Table II, plays piano, can carry a tune easily. Of mother's three sibs deceased, one brother possessed a facility in extemporizing like his father, but never studied music much. Mother's mother not musically expressive, but has great love for music, no music in her ancestry as far as known. Mother's father a musician, at an early age taken on concert tours displaying an unusual talent for extemporizing characteristic sketches on any subject, later an instrumental teacher, conductor, composer, director, musical lecturer, did not sing. Mother's father's brother, a church organist, bass singer, piano tuner, harmony teacher. Mother's father's mother, an oratorio singer, sang lovely old folk songs to her grand-children. Mother's father's mother's brother, a conductor of choir festivals, source of great musical inspiration to his nephew. Mother's father's father owned a piano store and small musical library. Mother's father's father's father a choral leader, taught singing school, published a book of singing exercises.

Paternal side: Father IV 11, musical ancestral items same as those for paternal side of V 11.

R V 15, female, Table II, plays piano and cello, arranges ensembles for cellos and violin, a soprano.

Sib: V 14, Table II, plays piano, violin by ear, carries a tune easily.

Maternal side: Mother, IV 22, Table II, sings contralto, teacher of voice and piano, choral director. Ancestral musical items same as those for V 11.

Paternal side: Father sings a bit out of tune, does not play an instrument, no musical instruments in the home of his parents. Father's father sang a little.

R V 16, male, Table II, plays cello and alto horn.

Sibs: V 17, Table II. One sister played the piano. No musical items for one brother and two sisters deceased.

Maternal side: Mother played the piano and the pipe organ, sang contralto. Mother's mother played melodeon and reed organ. Mother's mother's mother not musical. Mother's mother's father, bass singer, led choir. Mother's mother's father's mother sang in choir. Mother's father, a minister, bass singer, leader of choir.

Paternal side: Father, amateur violinist. No musical items known in his family.

R V 3, female, Table II, sings soprano.

Sib: One sister cannot sing on pitch, likes music but knows little about it.

Maternal side: Mother sang soprano, played the guitar. One of mother's two brothers sang some, mother's mother sang soprano, mother's father sang bass.

Paternal side: Father neither played nor sang, does not care for music, opposed daughter's study of music. Father's mother not musical. Father's father sang, played the cornet.

Table III. *Musical data classified: Alpha group*

				Musical Capacities				Environment			Musical Ratings					
Indv. Ref.	Sex	Age	Pitch	Int.	Time	Memory		Youth Home	Com.	Ad. Com.	Educ.	Act.	Crea. Abil.	Emo. Reac.	Daily Role	Gen. Educ.
A IV 12	M	47	Exc.	V.S.	Ave.	Sup.		A	A	A	A*	A*	A	A	A	A
A IV 11	F	57	Exc.	Poor	V.P.	H.A.		E	C	A	E	E	E	N.R.	N.R.	E
A IV 13	M	51	L.A.	Ave.	Poor	——		E	C	C	E	E	E	C	N.R.	C
A IV 10	M	61	Sup.	Ave.	Poor	Exc.		A	A	A	A	A	A	A	C	A
A IV 9	F	47	Ave.	Exc.	L.A.	Ave.		C	A	A	E	E	E	A	E	A
A V 3	F	13	V.S.	Exc.	Exc.	H.A.		C	C							
A V 4	M	12	V.S.	Sup.	V.S.	Ave.		C	C							
A III 4	F	73	Exc.	Ave.	Poor	N.R.		E	C	A	E	E	E	A	N.R.	N.R.
A IV 2	M	56	Exc.	Exc.	Ave.	Exc.		A	A	A	C	A	C	A	A	A
A V 1	F	12	Sup.	Exc.	Exc.	Sup.		C	C							
A V 2	M	10	V.S.	V.S.	Exc.	Exc.		C	E							

Classification of musical activity:

Group A—IV 12, 10, 2; group C—None; group E—III 4; IV 11, 9, 13; too young to classify—V 1, 2, 3, 4.

Classification of talent profiles:

Superior—IV 12; V 1, 2, 4; Excellent—IV 10, 2; V 3; Average—III 4; IV 11, 9; Poor—IV 13.

General comment:

III 4, (average profile consort is not living, has one child with an average profile; IV 10 and 9 (excellent and average profiles) have two children with excellent and superior profiles; IV 2 (excellent profile), consort not measured, has two children with superior profiles.

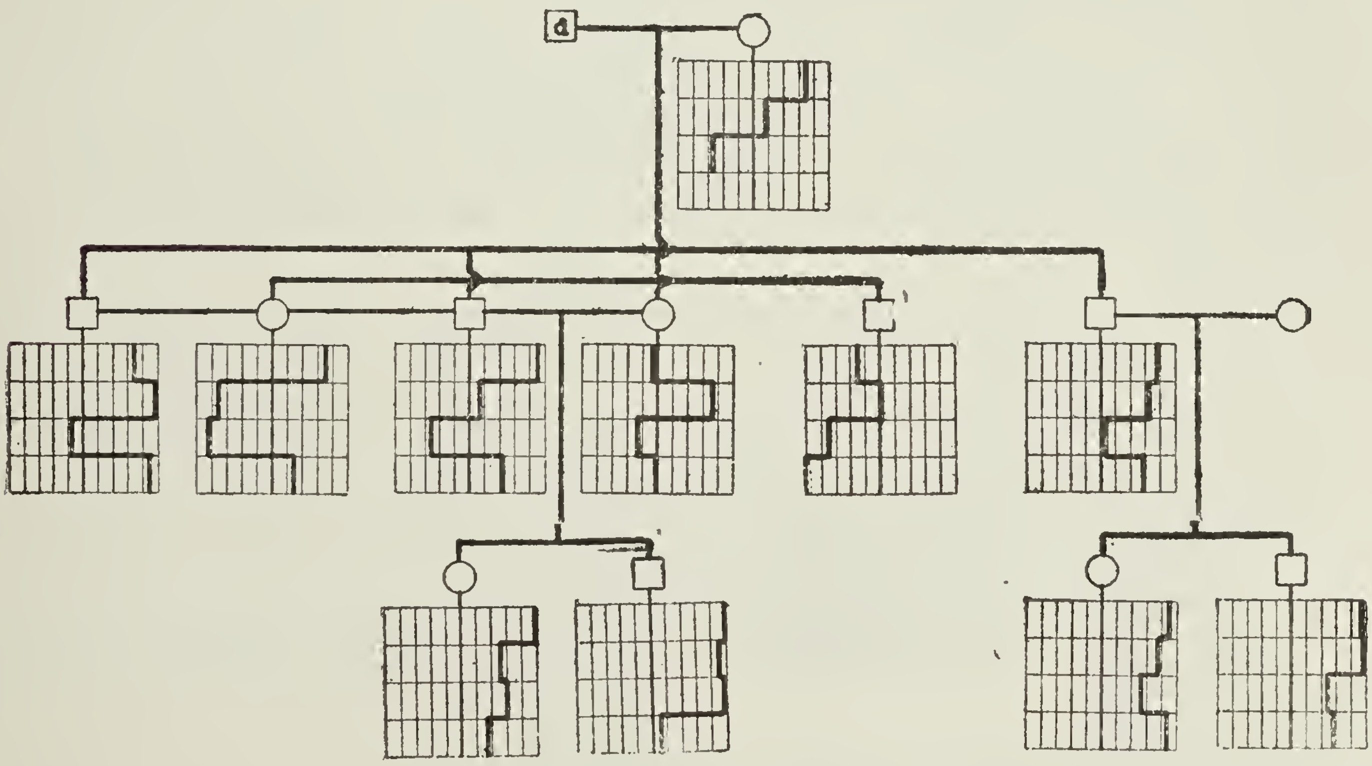

FIG. 3. Talent Pedigree Chart: Alpha Group.

Reference numbers from left to right, for the first row, III 3(deceased), 4; for the second row, IV 12, 11, 10, 9, 13, 2, 1 (did not take the tests); for the third row, V 3, 4, 1, 2.

Age range—73 to 10 years.

Family Musical History: Alpha group

A IV 2, male, Table III, plays piano and cabinet organ, carries tune easily.

Sibs: IV 10, sings bass, played cabinet organ and piano; IV 12, composer, plays piano, does not sing. Table III. IV 3, had few lessons on cornet, but never pursued study of music.

Maternal side: Poetical strain. Mother sang a little in church, exceedingly fond of music, musical temperament. Mother's mother sang in church choir of her son-in-law's father, II 12, a musician.

Paternal side: Father played church organ, conducted music in church services, developed, improved and sold musical instruments. Of father's three brothers, III 14, was a distinguished musician, pianist, educator; another was in the music business. Father's father, musical educator, director of church music, teacher.

A IV 9, female, Table III, played piano in youth, can carry a tune easily.
Sibs: Two brothers died under age of four. Two sisters play piano, one of them sings soprano. Brother profoundly affected by music.
Maternal side: Mother III 4, Table III, plays no instrument, easy to carry a tune. Of mother's four sisters, one died in infancy, one sang contralto, another sang soprano, a third showed some artistic ability in painting. Mother's brother not musically expressive. Mother's mother and sibs appreciated music in general. One of mother's mother's brothers a linguist. Mother's father alive to music but more inclined to literature. Music out of harmony affected the family physically, made them ill. Mother's father's three brothers and father sang in the home, one brother played the flute.
Paternal side: Father fond of music, no training, encouraged music in community.

A IV 11, female, Table III, sang out of tune at school. Played piano before age 14 only.
Sibs: One brother IV 13, Table III, could not carry a tune, plays no instrument. No musical items concerning two other sibs.
Maternal side: Mother sang some as a girl. Mother's father could not carry a tune, very skillful with his hands.
Paternal side: Literary tendency. Father, not especially musical, sang out of tune, fond of music, interested in literature. Father's brother sang in Yale Glee Club.

Classification of musical activity: [Lambda Group]
Group A—III 9; group C—IV 8, 23; group E—III 10; IV 7, 10, 11, 12, 16, 21, 25; too young to classify—IV 27; V 5.

Classification of talent profiles:
Superior—III 9; IV 8, 12, 23; V 5; excellent IV 7, 11, 16; average—III 10; IV 10, 21, 25, 27; Poor—None.

General comment:
III 9 and 10 (superior and average profiles) have four children (one superior, two excellent, and one average); IV 11 and 12 (excellent and superior profiles) have one child with a superior profile.

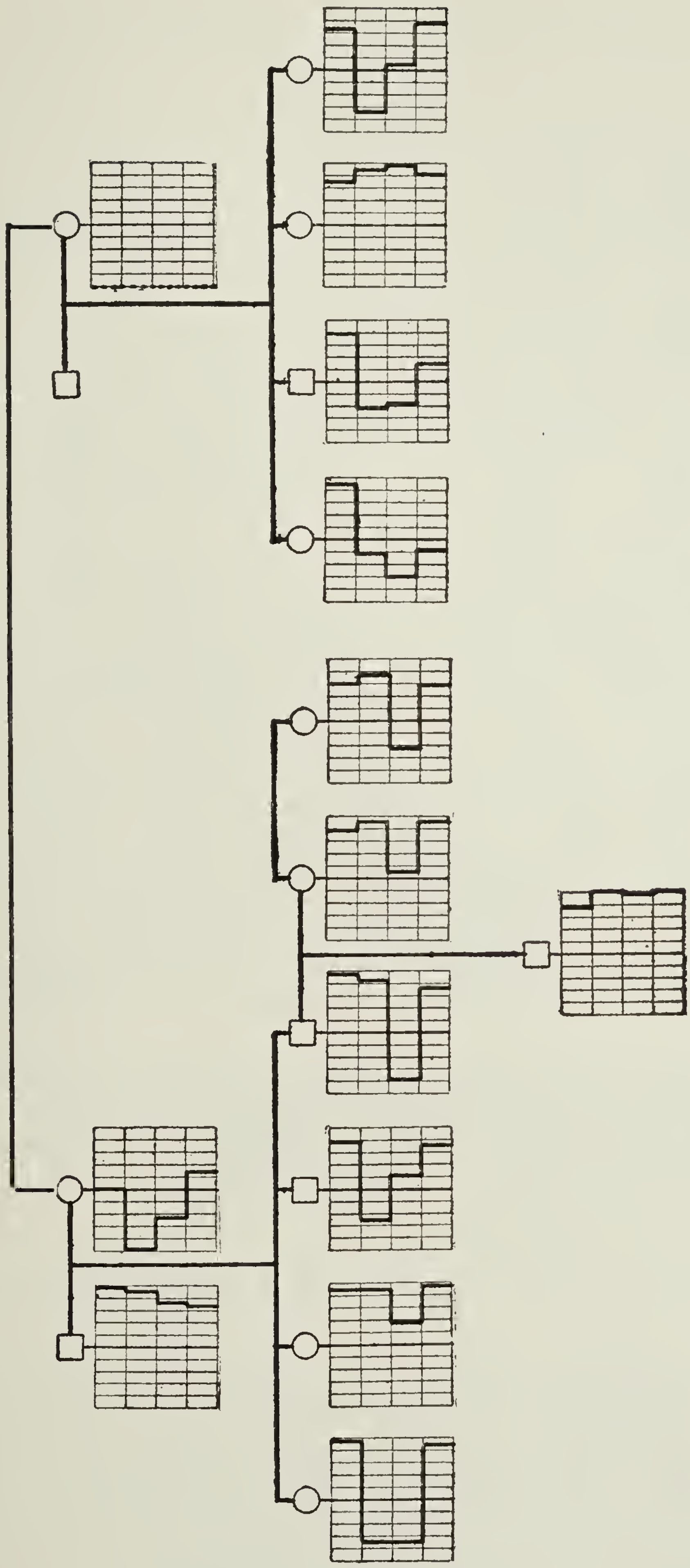

Fig. 4. Talent Pedigree Chart: Lambda Group.

Reference numbers from left to right, for the first row, III 9, 10, 14 (did not take the tests), 13; for the second row, IV 7, 8, 10, 11, 12, 16, 21, 25, 23, 27; for the third row, V 5.

Age range, 66 years to 9 years.

Table IV. *Musical data classified: Lambda group*

			MUSICAL CAPACITIES				MUSICAL RATINGS								
							ENVIRONMENT								
INDV. REF.	SEX	AGE	PITCH	INT.	TIME	MEMORY	YOUTH HOME	YOUTH COM.	AD. COM.	EDUC.	ACT.	CREA. ABIL.	EMO. REAC.	DAILY ROLE	GEN. EDUC.
L III 9	M	66	V.S.	Sup.	Exc.	Exc.	E	E	A	A*	A	C	A	N.R.	A
L III 10	F	62	Ave.	V.P.	Poor	H.A.	E	E	C	C	E	E	E	E	C
L IV 11	M	39	V.S.	Sup.	Poor	Exc.	A	A	C	E	E	E	N.R.	E	A
L IV 10	M	36	Exc.	Poor	H.A.	Exc.	A	A	C	E	E	E	N.R.	E	C
L IV 8	F	28	Sup.	Sup.	H.A.	V.S.	A	A	A	A	C	E	C	N.R.	C
L IV 7	F	27	V.S.	Poor	Poor	Sup.	C	A	A	C	E	E	C	E	C
L IV 12	F	39	Exc.	Sup.	Ave.	Sup.	E	E	C	E	E	E	C	N.R.	E
L V 5	M	8	Exc.	V.S.	V.S.	V.S.	E	E							
L III 13	F	58	——	——	——	——	E	E	C	E	E	E	C	E	E
L IV 21	F	36	Sup.	L.A.	Poor	Ave.	C	E	C	E	E	E	C	N.R.	A
L IV 23	F	34	Exc.	Sup.	V.S.	Sup.	C	E	C	C	C	E	C	E	A
L IV 25	M	31	Exc.	Poor	L.A.	H.A.	E	E	C	E	E	E	C	N.R.	A
L IV 27	F	17	Exc.	Poor	Ave.	Exc.	C	C							
L IV 16	F	49	Exc.	Exc.	Poor	Exc.	C	E	E	E	E	E	C	N.R.	E
L IV 1	M	27	Exc.	Poor	Ave.	L.A.	E	E	A	E	C	E	C	C	E

Family Musical History, Lambda Group

L IV 8, female, Table IV, teacher of piano in school of music, soprano soloist.

Sibs: IV 7, sings mezzo-soprano, plays piano; IV 10, plays clarinet, carries a tune and whistles; IV 11, plays cello, carries a tune easily. Table IV.

Maternal side: Mother, III 10, Table IV, sings soprano, played church piano when younger; has one brother and four sisters, one sister, III 13, recorded in Table IV, one sister, III 24, considered a professional pianist; one brother played piano as an avocation. No musical items concerning others. Mother's father, a minister, could not carry a tune. One maternal uncle played piano.

Paternal side: Father III 9, Table IV, choral conductor, conservatory director, organist, musical educator. Of his six sibs, three died in infancy, no musical expression noted in the other three. No music heard in the home of his parents.

L V 5, male, Table IV, studying piano.

Sibs: One sister and brother below age of 7, both singing solos in Sunday School.

Maternal side: Mother IV 12, Table IV, sings soprano, does not play. Mother's sibs, six in number, one sister sang alto and played the reed organ, three other sisters sang soprano but played no instrument. IV 16, a sister, Table IV, sings soprano. All of them often joined in family group singing. Mother's father played the clarinet and fife, sang tenor, and led family in singing. Mother's mother sang soprano.

Paternal side: Father IV 11, Table IV, sib of L IV 8.

L IV 21, female, Table IV, plays no instrument, difficult to carry a tune.

Sibs: IV 23, sings second soprano in church choir and choral union, plays piano; IV 25, whistles a tune, plays no instrument; IV 27, alto in glee club, studying piano; Table IV. IV 26, not measured, no musical expression.

Maternal side: Mother, III 13, Table IV, at one time soprano in church choir, plays no instrument, did not handle the measurements satisfactorily. Mother's sister, III 24, a professional pianist. Mother's brother played the piano as an avocation. Two sisters not musical. Mother's mother considered source of music in the family. Mother's father could carry a tune but not musical.

Paternal side: Father a minister, could not carry a tune. No member of his family, parents and three sibs, was musical.

L IV 1, male, Table IV, plays mando-cello, choir boy.

Sib: One sister, studied piano but played poorly.

Maternal side: Mother neither sang nor played an instrument.

Paternal side: Father an engineer, neither sang nor played. No music heard in his parental home.

L IV 12, female, Table IV, sang soprano, plays no instrument.

Sibs: IV 16, Table IV, sings soprano in chorus occasionally. All sibs joined in singing each evening at the parental home. Three sisters sang soprano, one sister sang also and played the melodeon some.

Maternal side: Mother sang soprano in the family singing.

Paternal side: Father played the flute, clarinet and fife, sang tenor in the home.

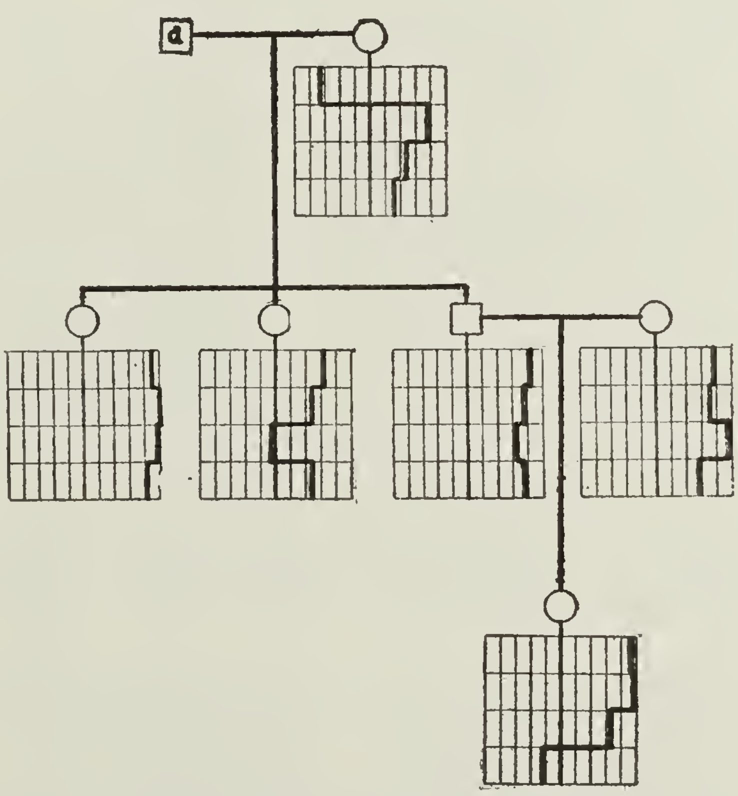

FIG. 5. Talent Pedigree Chart: Gamma Group.

Reference numbers from the left to the right, for the first row, II 9 (deceased), 8; for the second row, III 2, 4, 4, 6; for the third row, IV 2.

Age range, 80 years to 9 years.

Classification of musical activity:

Group A—III 2, 5; group C—II 8; III 4; group E—III 6; too young to classify—IV 2.

Classification of talent profiles:

Superior—III 2; IV 2; Excellent—III 4, 5, 6; Average—II 8; Poor—None.

General comment:

II 8 (average profile) consort not living but would have ranked A in musical activity, has three children (two excellent and one superior); III 5 and 6 (both excellent profiles) have one child with a superior profile.

Table V. *Musical data classified: Gamma group*

INDV. REF.	SEX	AGE	PITCH (MUSICAL CAPACITIES)	INT.	TIME	MEMORY	ENVIRONMENT YOUTH HOME (MUSICAL RATINGS)	ENVIRONMENT YOUTH COM.	ENVIRONMENT AD. COM.	EDUC.	ACT.	CREA. ABIL.	EMO. REAC.	DAILY ROLE	GEN. EDUC.
G III 2	F	53	Sup.	V.S.	V.S.	Sup.	A	A	A	A*	A	A	A	A	E
G III 4	F	42	Exc.	Exc.	Ave.	Exc.	A	A	A	C	C	C	A	A	E
G III 5	M	39	Sup.	Exc.	Exc.	Exc.	A	A	A	A	A	C	A	A	A
G III 6	F	33	Exc.	Exc.	V.S.	Exc.	E	E	C	E	E	E	N.R.	C	E
G IV 2	F	9	V.S.	V.S.	Exc.	L.A.									
G II 8	F	80	Poor	Exc.	Exc.	H.A.	C	C	A	C	C	C	A	N.R.	E

Family musical history: Gamma group

G III 2, female, Table V, composer, choral director, could carry a tune, plays piano and violin.

Sibs: III 5, plays piano and pipe organ; III 4, plays piano, amateur singer. Table V. One brother deceased.

Maternal side: Mother II 8, Table V, plays piano, high soprano soloist. Of mother's three sisters, two were almost deaf, never did much in music, one played the piano beautifully. Of mother's two brothers, one not much interested in music, the other never played but sang in choruses. Mother's mother sang sorano delightfully. Mother's parents, devoted to music.

Paternal side: Father, pianist, conductor, no singing voice. Father's sister, soprano singer, teacher of voice. Father's father played church organ, sang some, teacher of his son. Father's mother cared for music but did not play or sing.

G III 6, female, Table V, plays piano, carries a tune easily.

Sib: Brother distinctly musical, no training, plays and sings in amateur fashion.

Maternal side: Mother played piano, talented musically, painted. Mother's sister and brother not musical.

Paternal side: Father not musical but has an appreciative nature. Father's three sisters, one not musical, one a concert pianist in youth, one has a keen literary sense.

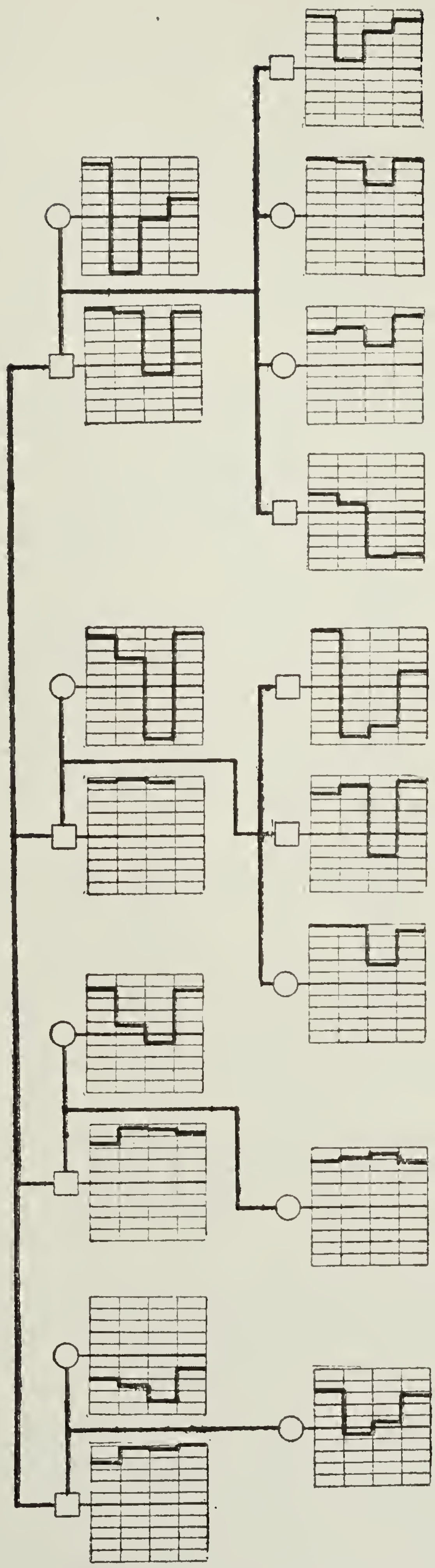

Fig. 6. Talent Pedigree Chart: Epsilon Group.
Reference numbers from the left to the right, for the first row, III 9, 8, 21, 20, 30, 29, 31, 32; for the second row, IV 5, 19, 33, 34, 35, 36, 37, 38, 39.
Age range 55 years to 13 years.

Classification of musical activity: [Epsilon Group]

Group A—III 9 30, 31; group C—None; group E—III 8, 20, 29, 32; IV 19, 33, 34, 36, 37, 38, 39; too young to classify—IV, 5, 35.

Classification of talent profiles:

Superior—III 9, 21, 30, 31; IV 19, 33, 34, 38, 39; Excellent—III 20, 29; IV 5, 37; Average—III 32; IV 35, 36; Poor—III 8.

General comment:

III 9 and 8 (superior and poor profiles) have one child with an excellent profile; III 21 and 20 (superior and excellent profiles) have one child with a superior profile; III 30 and 29 (superior and excellent profiles have three children (two superior and one average); III 31 and 32 (superior and average profiles) have four children (two superior, one excellent, and one average).

Table VI. *Musical data classified: Epsilon group*

			MUSICAL CAPACITIES				MUSICAL RATINGS								
							ENVIRONMENT								
INDV. REF.	SEX	AGE	PITCH	INT.	TIME	MEMORY	YOUTH HOME	YOUTH COM.	AD. COM.	EDUC.	ACT.	CREA. ABIL.	EMO. REAC.	DAILY ROLE	GEN. EDUC.
E III 9	M	45	Exc.	V.S.	V.S.	V.S.	A	A	A	A	A	A	A	A	A
E III 8	F	43	L.A.	Poor	Poor	L.A.	E	C	A	E	E	E	C	E	C
E IV 5	F	18	Exc.	Ave.	Ave.	Exc.	A	A							
E III 21	M	46	Exc.	V.S.	Sup.	Sup.	A	A	C	E	E	E	A	E	A
E III 20	F	47	Exc.	Ave.	Ave.	Exc.	C	C	C	E	E	E	A	E	C
E IV 19	F	21	Exc.	Sup.	Sup.	Exc.	C	A	N.R.	E	E	E	C	E	C
E III 30	M	53	V.S.	V.S.	V.S.	N.R.	A	A	A	C	A	C	N.R.	E	A*
E III 29	F	51	Sup.	Exc.	V.P.	Sup.	C	A	C	E	E	E	E	E	E
E IV 33	F	25	V.S.	V.S.	H.A.	Sup.	C	A	C	E	E	E	A	E	C
E IV 34	M	19	Exc.	Sup.	L.A.	Sup.	C	C	C	E	E	E	E	E	C
E IV 35	M	13	V.S.	V.P.	Poor	H.A.	C								
E III 31	M	55	V.S.	Sup.	Ave.	Sup.	A	A	A	A	A	A	A	E	A
E III 32	F	52	Sup.	V.P.	Ave.	H.A.	C	A	A	C	E	E	C	E	E
E IV 36	M	25	H.A.	Ave.	Poor	Poor	C	C	N.R.	E	E	E	E	E	A
E IV 37	F	22	Exc.	Exc.	H.A.	Sup.	C	A	N.R.	C	E	C	C	C	C
E IV 38	F	20	V.S.	V.S.	Exc.	V.S.	C	A	N.R.	C	E	C	C	C	C
E IV 39	M	19	Sup.	Ave.	Exc.	Sup.	C	A	N.R.	E	E	E	E	N.R.	C

E IV 5, female, Table VI, plays piano, could not carry a tune until age of 7.

Sibs: None.

Maternal side: Mother, III 8, Table VI, does not play, impossible to sing. Mother's sister and two brothers not musically expressive. Mother's mother played piano in very elementary fashion. Mother's father, no items.

Paternal side: Father, III 9, Table VI, composer, plays piano, bass singer. Father's three brothers: III 21 plays piano, carries tune easily; III 30, plays piano, violin, and trombone, sings second bass; III 31, class chorister, sings first bass, plays violin and any brass instrument; Table VI. Father's mother, an accomplished musician, sings mezzo-soprano. Of father's mother's three sibs, one was a crusader and teacher in choral singing and a music teacher in public schools. Father's mother's parents, neither musically expressive but toiled steadily to give their children a musical education. Father's father, critic and lover of music, fiddled some, played simple melodies on piano. Of father's three sibs, one sister sang and played piano some, and another sister sang contralto in church choir and played the piano. Father's parents, no musical items.

E IV 19 female, Table VI, plays piano, can carry a tune.

Sib: One brother, no musical comment.

Maternal side: Mother III 20, Table VI, does not play, did chorus singing. Mother's six sibs: two brothers deceased, one sister played guitar, another sister played the piano. Mother's mother ill many years. Mother's mother's father, church organist. Mother's father, no musical items.

Paternal side: Father III 21, Table VI, ancestral notes same as paternal ancestral notes of E IV 5.

E IV 33, female, Table VI, plays piano, can carry a tune but singing irritates her.

Sibs: IV 34, plays piano and mandolin, sings baritone; IV 35, plays piano and mandolin, easy to carry a tune. Table VI.

Maternal side: Mother, III 29, Table VI, plays cabinet organ and piano, can sing melodies. Mother's sister played the piano. Of mother's two brothers, one played violin, with no degree of skill, one played cello, the latter more musical than any of the others. Mother's mother played piano and sang in church choir. Mother's father very fond of music, played double bass in family orchestra.

Paternal side: Father, III 30, Table 6, ancestral notes same as paternal ancestral notes of E IV 5.

E IV 36, male, Table VI, played mandolin at one time, difficult to carry a tune.

Sibs: IV 37, plays piano, carries tune easily, composes some; IV 38, plays piano, sings alto, composes some; IV 39, plays violin, sings easily. Table VI.

Maternal side: Mother III 32, Table VI, plays piano, could carry a tune. Mother's six sibs: one sister, deceased, was very musical; one of four brothers not musical, one very musical, one fond of music and played the cello, one "music mad." Mother's mother not musical, did nothing in music, cared little for opera. Mother's father played no instrument but cared for music, stimulated and encouraged orchestras, opera, etc.

Paternal side: Father, III 30, Table VI, ancestral notes same as paternal ancestral notes of E IV 5.

Form of records for filing in the Eugenics Record Office Archives, Cold Spring Harbor, Long Island, N. Y.

The records for filing include a detailed report of individual items, general and musical; pedigree charts of a family group with a list of names of the charted individuals; family distribution blanks of musical talent; and test records of four measures of musical capacities for each individual.

Individual report. This report is a typewritten record of the results of an individual interview. In the order of points mentioned, such a report contains the date of interview; reference to chart number, and to the family distribution blank number; the full name of individual reported, with date and place of birth; names of consort, and children; names of parents, brothers and sisters; general education including name of schools, time spent in each, degrees received; chief occupations; vocational and avocational interests; musical environment during youth and adult life at home and in the community; musical education and training; musical activity; musical appreciation; musical memory and imagination; family musical history.

Pedigree charts. The list of the names of the charted individuals with the individual chart reference accompanied each pedigree chart as given above.

Original records of the measurements. The original record sheets and notes in each measurement are filed.

All records and reports of this investigation are considered confidential. For this reason the family and individual identifications are not available for publication.

Types of mating and progeny: based upon ancestral musical items

The question arises as to whether or not musical parents of musical stock tend to have musical children. The inquiry may be answered by a study of ten different combinations in which four individual types are the components, viz., a musical person of musical stock, a musical person of non-musical stock, a non-musical person of non-musical stock, a non-musical person of musical stock. Musical stock, as used in the following classification, may signify only one musical parent, or both parents musical, and may include musical grandparents, maternal, paternal or both. Non-musical stock refers to both parents as non-musical.

The term 'musical' is applied to those individuals who have been or are musically expressive. A very definite purpose of this study is an attempt to identify those individuals who may be musical, but who have not found expression by voice or instrument. This absence of expression may be due to various causes such as ill health, lack of opportunity, financial inadequacy, physical defects, no time for study.

In the classification which follows, the parents of many of the persons measured for musical capacities are not living. The musical information obtainable regarding these parents is based upon their musical expression or musical interest as reported by their children. Since the term 'musical,' meaning musical expression, must be used in that connection for all those not living, the same meaning is applied to those measured in order to be consistent. Even though many discrepancies arise in such a classification, the available data furnish examples of three of the ten possible combinations.

Musical person of musical stock mated to a musical person of musical stock. There are five matings of this type classified as musical with musical parentage. In two cases only one parent was musical. Of twenty-two children belonging to these five matings, eleven are matured, six under the age of nine years, four died in infancy. Ten of the matured children are musical, the other one whose normal growth has been inhibited shows no musical tendencies.

Non-musical person of non-musical stock mated to a non-musical person of non-musical stock. Six matings of this type occur comprising twelve individuals with non-musical parentage. Of twenty-seven children, two died in infancy, twenty-five are matured and classed as non-musical. Several of these have studied on a musical instrument earlier in life but the inclination soon died and they have not been musically interested since.

Musical person of musical stock mated to a non-musical person of non-musical stock. Ten matings of this type consisting of 20 individuals were found. The musical person of musical stock in 7 matings is the man and in 3 matings it is the woman. Of 25 children varying in age from 8 years to approximately 30 years, 1 died in infancy, 5 are too young for classification, no information was obtained concerning two others, 6 of the remaining are musical and 11 non-musical.

The remaining eleven matings are distributed among six different type combinations, namely, two musical persons both of non-musical stock; two-non-musical persons of musical stock; two musical persons, one of musical stock, the other of non-musical stock; two non-musical persons, one of musical stock, the other of non-musical stock; one non-musical person of non-musical stock mated to a musical person of non-musical stock, one non-musical person of musical stock mated to a musical person of non-musical stock. One more combination remains, that in which a *musical person of musical stock mates with a non-musical person of musical stock.* No example of this type occurred. The number of matings classified under each of these type combinations are too few and children of these matings too young for a sufficient grouping to throw any light on the distribution.

The following tentative conclusions are similar to those found by Davenport (1, p. 48). Those parents who are musical and whose ancestry is musical on one or both sides tend to have musical children; those parents who are not musical and have a non-musical ancestry on both sides tend to have non-musical children; those parents, one of whom is musical with musical ancestry, the other non-musical of non-musical ancestry have children of both types.

Discussion of data on the inheritance of musical capacities

Family distribution of capacities. This material presented in the form of tables for each capacity differs from any other material on the inheritance of musical talent of which the writer is cognizant in that we are not measuring what a person can do or cannot do in musical expression, but we are measuring the nicety, the accuracy, or the delicacy with which individuals receive musical impressions through the channels of pitch, intensity, time and memory. Since we are unable to see these characteristics or traits, our only avenue of approach is the measure of each elementary capacity by the methods previously explained. The most direct method of observing family relationships in these capacities is the table of types of mating and the distribution of these capacities for the offspring of each type. By accumulating all the ranks from 1 to 100 into three groups of poor (1-29), average (30-69), superior (70-100), six types of matings are represented viz., Superior x Superior (SxS), Superior x Average (SxA), Average x Average (AxA), Superior x Poor (SxP), Average x Poor (AxP) and Poor x Poor (PxP). For each type the children are distributed according to their group as S (sup.), A (ave.) and P (poor).

Table VII. *Sense of pitch*

Matings		Offspring			
Type	No.	Sup.	Ave.	Poor	Total
1. S x S	8	15	1	0	16
2. S x A	4	11	0	0	11
3. A x A	1	1	0	0	1
4. S x P	0	0	0	0	0
5. A x P	0	0	0	0	0
6. P x P	0	0	0	0	0
One parent only measured.					
S x —	2	2	1	0	3
A x —	1	2	0	0	2
P x —	2	2	0	0	2
	18 matings	35	3	1	39 offspring
Neither parent measured.					
Type unknown	No.	Sup.	Ave.	Poor	
— x —	1	4	0	0	
— x —	1	2	1	0	
— x —	1	3	0	0	
— x —	1	2	2	0	
— x —	1	4	0	0	
	5	15	3	0	

Only three of the six types of mating are represented in the above table. These three types indicate that when both parents were superior in pitch discrimination all the children but one were superior in pitch discrimination, the one child with average rank lacked four units of having a superior rank; when one parent was superior and the other average all the children were superior; the third type, A x A, is an insignificant mating (only one child).

Table VIII. *Sense of intensity*

Matings			Offspring		
Type	No.	Sup.	Ave.	Poor	Total
1. S x S	4	6	0	1	7
2. S x A	3	5	1	0	6
3. A x A	1	0	0	1	1
4. S x P	4	5	4	2	11
5. A x P	1	0	1	0	1
6. P x P	0	0	0	0	0
One parent only measured.					
S x —	3	6	1	0	7
A x —	1	1	0	0	1
P x —	1	0	3	0	3
	18 matings	23	10	4	37 offspring

Neither parent measured.

Mating			Offspring	
Type unknown	No.	Sup.	Ave.	Poor
— x —	1	4	0	0
— x —	1	3	0	0
— x —	1	2	1	0
— x —	1	2	2	0
— x —	1	1	1	2
	5	12	4	2

Five types of matings are represented in the above table, three of which have three or more matings. If both parents ranked superior in intensity, all the children were superior except one who was poor. If one parent was superior and the other average all the children were superior except one average record. If one parent was superior and the other poor, the children were superior, average, and poor.

Table IX. *Sense of time*

Matings			Offspring		
Type	No.	Sup.	Ave.	Poor	Total
1. S x S	3	5	0	0	5
2. S x A	4	3	2	1	6
3. A x A	1	2	1	1	4
4. S x P	3	0	5	3	8
5. A x P	2	3	0	0	3
6. P x P	0	0	0	0	0
One parent only measured.					
S x —	1	2	1	0	3
A x —	2	3	1	0	4
P x —	2	0	2	2	4
	18 matings	18	12	7	37 offspring

Neither parent measured.

Matings			Offspring	
Type unknown	No.	Sup.	Ave.	Poor
— x —	1	3	1	0
— x —	1	2	1	0
— x —	1	0	2	1
— x —	1	4	0	0
— x —	1	1	2	1
	5	10	6	2

Three of the five types represented in the above table have three or more matings. When both parents were superior all the children were superior. If one parent was superior and the other average, the offspring were superior, average, and poor (lacked two units of being average). If one parent was superior and the other poor the offspring were average and poor.

Table X. *Tonal memory*

	Matings			Offspring		
	Type	No.	Sup.	Ave.	Poor	Total
1.	S x S	4	4	1	0	5
2.	S x A	7	14	2	1	17
3.	A x A	0	0	0	0	0
4.	S x P	0	0	0	0	0
5.	A x P	0	0	0	0	0
6.	P x P	1	0	1	0	1
One parent only measured.						
	S x —	3	6	1	0	7
	A x —	1	3	0	0	3
		16 matings	27	5	1	33 offspring

Neither parent measured.

Mating Type unknown	No.	Sup.	Ave.	Poor	No rec.
— x —	1	3	0	0	1
— x —	1	3	0	0	
— x —	1	3	0	0	
— x —	1	0	4	0	
— x —	1	2	2	0	
	5	11	6	0	1

Again the representation is accumulated in three types, similar to those for pitch. If both parents were superior, the children were superior and average. If one parent was superior and the other average, the children were superior, average and poor. The one mating of the type P x P is insignificant (only one child).

Table XI. *Musical talent profiles*

Matings		Offspring			
Type	No.	Sup.	Ave.	Poor	Total
1. S x S	6	9	1	0	10
2. S x A	5	12	2	0	14
3. A x A	1	0	1	0	1
4. S x P	1	1	0	0	1
5. A x P	0	0	0	0	0
6. P x P	0	0	0	0	0
One parent only measured.					
S x —	2	4	0	0	4
A x —	2	3	1	0	4
P x —	1	0	1	2	3
	18 matings	29	6	2	37 offspring

Neither parent measured.

Mating		Offspring		
Type unknown	No.	Sup.	Ave.	Poor
— x —	1	4	0	0
— x —	1	3	0	0
— x —	1	3	0	0
— x —	1	3	1	0
— x —	1	1	3	0
	5	14	4	0

The above table of family distribution of talent profiles shows that if both parents had superior talent profiles all their children had superior talent profiles with the exception of one average profile; if one parent had a superior talent profile and the other an average profile, all the children had superior talent profiles with the exception of two average profiles.

Method of inheritance. Statements of apparent indications of the method of inheritance of each capacity are necessarily tentative for the following reasons: first, the paucity of data which is evidenced by the few matings for specific types with an average of two offspring for each mating; second, the group studied is select, shown by the accumulation of data within the upper ranks so that poor ranks are relatively few; third, the generation scope is limited, most of the records are persons in only two generations of a family group. In spite of these limitations, the distribution of the offspring of those types of mating represented by the present data suggests segregation of superior capacity from average and poor capacities. In those tables where examples of the average x average type of mating occur the offspring, have superior, average, and poor capacities, which suggests an independent transmission of factors determining the different capacities. There are indications of the superior capacity dominating over the average and poor capacities of the same measure. The inheritance of musical capacities seems, indeed, to follow Mendelian principles but the method of inheritance is so complex that it is impossible now to state how many factors may be present.

Presence or absence of determiner. We are not yet in position to say anything authoritative about the relation of these capacities to specific determiners, and the data here available are not adequate for any elaboration in that direction; but it is interesting to anticipate what might be shown if certain assumptions were valid.

In order to present the relation between parents and offspring in terms of the assumed presence and absence of a representative determiner for the superior capacity in each measure, the presence of a determiner may be represented by a large letter as P (Pitch), I (intensity), T (time), and M (memory) respectively, with the corresponding small letter representing the absence of such a determiner so that hypothetical gametic formulae for the superior, average, and poor capacities may be represented in the case of pitch by PP, Pp, and pp; in the case of intensity by II, Ii, and ii; in the case of time by TT, Tt, and tt; in the case of memory by MM, Mm, and mm.

Table XII. *Pitch*

Matings Type	No.	Offspring Realized			Expected
		Sup.	Ave.	Poor	
1. PP x PP	8	15	1	0	All PP
2. PP x Pp	4	11	0	0	½ PP + ½ Pp
3. Pp x Pp	1	1	0	0	¼ PP + ½ Pp + ¼ pp
4. PP x pp	0	0	0	0	All Pp
5. Pp x pp	0	0	0	0	½ Pp + ½ pp
6. pp x pp	0	0	0	0	All pp

Table XIII. *Intensity*

Matings Type	No.	Offspring Realized			Expected
		Sup.	Ave.	Poor	
1. II x II	4	6	0	1	All II
2. II x Ii	3	5	1	0	½ II + ½ Ii
3. Ii x Ii	1	0	0	1	¼ II + ½ Ii + ¼ ii
4. II x ii	4	5	4	2	All Ii
5. Ii x ii	1	0	1	0	½ Ii + ½ ii
6. ii x ii	0	0	0	0	All ii

Table XIV. *Time*

Matings Type	No.	Offspring Realized Sup.	Ave.	Poor	Expected
1. TT x TT	3	5	0	0	All TT
2. TT x Tt	4	3	2	1	½ TT + ½ Tt
3. Tt x Tt	1	2	1	1	¼ TT + ½ Tt + ¼ tt
4. TT x t t	3	0	5	3	All Tt
5. Tt x t t	2	3	0	0	½ Tt + ½ tt
6. t t x t t	0	0	0	0	All tt

Table XV.

Matings Type	No.	Offspring Realized Sup.	Ave.	Poor	Expected
1. MM x MM	4	4	1	0	All MM
2. MM x Mm	7	14	2	1	½ MM + ½ Mm
3. Mm x Mm	0	0	0	0	¼ MM + ½ Mm + ¼ mm
4. MM x mm	0	0	0	0	All Mm
5. Mm x mm	0	0	0	0	½ Mm + ½ mm
6. mm x mm	1	0	1	0	All mm

The cause of a superior capacity in any or all these measures is not definitely known. Up to the present time we have assumed that an individual with superior pitch discrimination possessed a very sensitive ear for discrimniatng pitches and that one with poor pitch discrimination did not possess a sensitive ear in that respect. This does not necessarily mean that an individual with poor pitch discrimination has a defective ear, in fact we are inclined to regard this as we would short stature contrasted with tall stature or blue eyes in contrast with brown eyes, merely a recognized individual difference in degree. The cause of this individual variation may be due to certain central factors as well as structural and functional differences in the inner ear mechanism. This raises the question as to whether or not a single factor might determine superior capacity.

Problem of different age groups

Recognized sources of error in dealing with individuals ranging in age from 8 to 80 years consist first, in the fact that for adults of all ages we have but one percentile rank table for each capacity; second, any capacity may or may not be affected by old age; third, difficulty in obtaining a reliable measure of individual capacity may increase with age. To what extent these sources of error exist we do not know.

The curves below show the variation of this group in rank for each capacity throughout the age range. With a greater number of cases these curves would be smooth; but, even so, a decrease in rank would probably accompany any increase in age beyond a certain point.

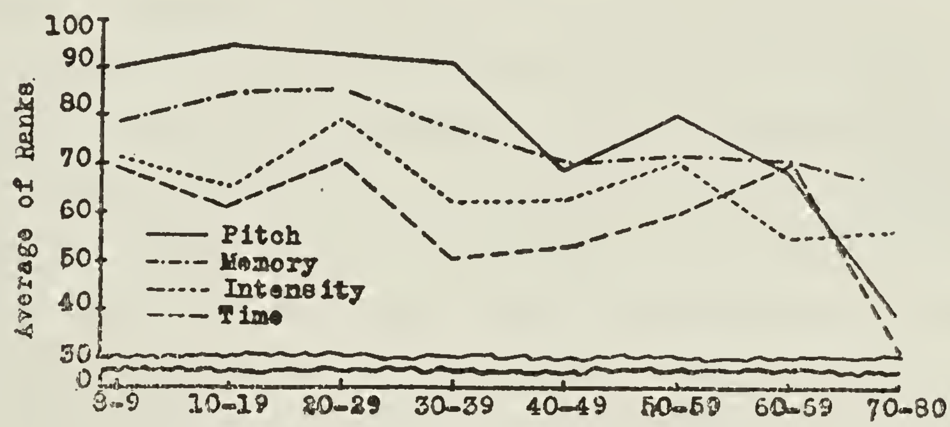

Fig. 7. Variation of rank with age.

Even though this group is a selected one, small in number, variable from one extreme to the other, in age, in musical capacities, in musical activities, etc., we may be able to lessen the sources of error stated above, first, by establishing at least two percentile ranks for those above the age of 40 years, one for an age span of approximately 45 to 65 years, the other for all above 65 years; second, by a study of the variation in musical capacities with increase in age by measuring the same individuals at successive periods of five years or less.

Table XVI. *The measures of musical capacities for all those above the age of 65*

Indiv.	Age	Pitch Rank	Intensity Rank	Time Rank	Memory Rank
1	66	99	95	87	83
2	67	40	7	100	23
3	73	84	58	24	No record
4	80	11	19	4	No rank
5	80	18	87	73	65

From the supplementary data, individuals 1 and 5 would be considered musical, individuals 2, 3, and 4 non-musical. This table indicates that we may obtain reliable measurements from a person 66 years of age, but it does not affrm or deny the reliability of the measurements obtained by those above the age of 66. In the two cases of persons 80 years of age, number 4 is not musical, hence her low record may be reasonably reliable; number 5 is musical, all ranks excepting pitch for this individual are high average or above. Uncontrollable subjective disturbances entered into the pitch measurement for individual 5, so that it may not represent her ultimate capacity in pitch. The writer would advise giving the measurements to all capable members of a family regardless of age.

Relation of musical capacities to supplementary data

For this particular group of persons a standard classification of supplementary factors has been proposed in a previous section. These supplementary factors include (1) musical environment during childhood in the home and (2) in the community, (3) musical education and training, (4) musical activity, (5) emotional experiences resulting from musical stimulation, (6) rôle of music in daily thought (7) creative musical expression, (8) general non-musical education beyond high school. The triple classification for each factor has been indicated by A, the highest rating; C, the middle rating; and E, the lowest rating. The talent profiles have been previously classified into superior, excellent, average and poor. In terms of these two classifications the correlation of the talent profiles with each of the supplementary factors will be shown in the following tables.

Table XVII. *Talent profiles and musical environment in the home during childhood*

Musical Environment	Musical capacities: Sup.	Exc.	Ave.	Poor	Total
A	13	8	1	0	22
C	13	10	9	1	33
E	5	5	7	4	21
Total	31	23	17	5	76 cases

A distribution is presented in Table XVII showing the number of individuals falling in the upper, middle and lower groups of musical environment in the home during childhood, and their relative grouping with regard to classification of the talent profiles into superior, excellent, average, and poor. Fifty-nine per cent of those who were in an A environment at home during childhood have superior talent profiles. Thirty-six per cent have excellent talent profiles, and five per cent average talent profiles. Of those with an E environment, twenty-four per cent have superior and excellent profiles respectively, thirty-three per cent average and nineteen per cent poor profiles. If the relation between these two corresponded exactly all those with A environment at home would have superior talent profiles, all those with E environment at home would have poor talent profiles. As it is nearly half of those with an E environment at home are excellent or above and the rest are average or below.

Table XVIII. *Talent profiles and musical education and training*

Musical Education and Training		Musical capacities				
		Sup.	Exc.	Ave.	Poor	Total
	A	9	3	0	0	12
	C	8	6	5	0	19
	E	8	8	9	5	30
		25	17	14	5	61 cases

Twenty per cent of the cases are persons with a superior musical education and training. All of these have excellent and superior profiles. Fifty per cent of the cases have had little or no musical education and training. They represent all four degrees of musical talents with twenty-six per cent of them excellent and superior. At least one-fourth are deserving of a musical education and they had none. Here again expectation is verified, superior capacities are not limited to those with superior musical training. The number of persons with superior capacities who have had no musical education is the same as those with superior capacities who have had superior musical education.

All those with poor capacities have had little or no musical training.

Table XIX. *Talent profiles and general education*

General Education		Musical capacities				
		Sup.	Exc.	Ave.	Poor	Total
	A	14	7	5	2	28
	C	7	5	3	2	17
	E	4	5	6	1	16
		25	17	14	5	61 cases

General education refers to the education received after graduation from high school, although the E group includes a few with incomplete high school education. Of those with little or no education beyond high school twenty-five per cent made superior records in the talent measurements, fifty-six per cent rank excellent and above. Forty per cent of those with poor talents rate in the highest class of general education; sixteen per cent of the persons with superior talents rate in the lowest educational group. This table shows no indication of those with the highest talent records to be in the group of the best education. In fact, the tables XVII, XVIII, XIX show little tendency of correlation between the factors presented.

Table XX. *Talent profiles and musical activity*

Musical Activity		Musical capacities				
		Sup.	Exc.	Ave.	Poor	Total
	A	8	5	0	0	13
	C	8	1	3	0	12
	E	9	11	12	5	37
		25	17	15	5	62 cases

Thirty-six per cent of those who are superior in the musical capacities are not actively participating in musical expression. All those who have been or are the most active in musical expression have talent profiles ranking excellent or above. None of the five persons with poor capacities have expressed themselves in music. These data show that fifty-six per cent of those persons who are excellent and above in their capacities of tonal receptivity are not engaged in musical expression, vocal or instrumental.

The persons rated in musical activity include all those twenty years of age and above. Sixty-seven per cent. of these have superior and excellent charts. Of this superior group in musical capacities, forty-seven per cent. are rated E in musical activity. There are interesting facts noted in the supplementary data for these individuals which may account in part for their lack of participation in musical expression. In general, they are interested in music, all but one sing, play, or do both, some have had no opportunity to study, others have been nervous and ill, several are young mothers, or business men who have no time for it, and a few are studying piano and voice.

According to the data in Table XX the four measurements of musical capacities identify all those who rate highest in musical activity in addition to some who are not active in music. If we should be able to predict approximately by means of these four measurements those in the younger generation who will probably rate in the upper group of musical activity we will have advanced an important step in the direction of vocational guidance in music.

Table XXI. *Talent profiles and creative musical expression*

		Musical capacities					
		Sup.	Exc.	Ave.	Poor	Total	
Creative Musical Expression	A	7	1	0	0	8	
	C	6	4	1	0	11	
	E	12	12	15	5	44	
		—	—	—	—	—	
		25	17	16	5	63	cases

The phrase "creative musical expression" includes improvisation and composition. Such a rating excludes many who hear new melodies but never impart them; it excludes those who "seek the woods and make the organ improvise" until they are satisfied, those who invariably hear a melody (new to them) when reading poetry, those who are conscious of a previously unheard of melody at times of great exaltation.

This relation is similar to the last one in that we are comparing impression with expression. All those who are very expressive in musical creations are excellent and superior in the musical capacities but all those who are excellent and superior in the musical capacities are not improvisers or composers. Creative musical expression is not common in this group. No doubt many in the E rating possess creative power but a standard of guidance for rating of creative capacity is unstable at present.

Table XXII. *Talent profiles and emotional experiences Resulting from musical stimulation*

Musical capacities

Emotional Experiences	Sup.	Exc.	Ave.	Poor	Total
A	12	9	3	0	24
C	8	4	6	2	20
E	8	2	4	3	12
No record	1	2	2	0	5
	24	15	17	24	61

The A group includes those who have experienced stirring emotional reactions to music which are noticeably sustained or felt at various times.

Those who have experienced emotional states to the greatest degree accompanying musical stimulation are average and above in the musical capacities, with fifty per cent superior. Only twelve and one-half per cent of those superior in musical capacities have not experienced or do not recall emotional reactions to music. Not any of those with poor talent profiles have been especially "moved by music."

Table XXIII. *Talent profiles and rôle of music in daily life*

Musical capacities

Rôle of Music in Daily Life	Sup.	Exc.	Ave.	Poor	Total
A	8	4	0	0	12
C	2	6	1	0	9
E	10	6	9	4	29
No record	5	1	5	1	12
	25	17	15	5	62

Here again all those in the A class have excellent and superior talent profiles. Those in the E class have all four grades of grouped capacities: no consistent positive correlation is evident.

Comparison of highest five per cent. and lowest five per cent.

The lowest 5% was selected on the basis of the lowest talent profiles. Only five poor talent profiles occur in the whole group. Since 5% of the group is approximately four persons, the one poor profile for a woman 80 years old was excluded leaving four poor talent profiles for persons ranging in age from

40 years to 52 years. The four best talent profiles were selected from those 40 years of age or older so as to retain a similarity in age span between the two groups. These two groups are an extreme contrast in their talent profiles as shown below.

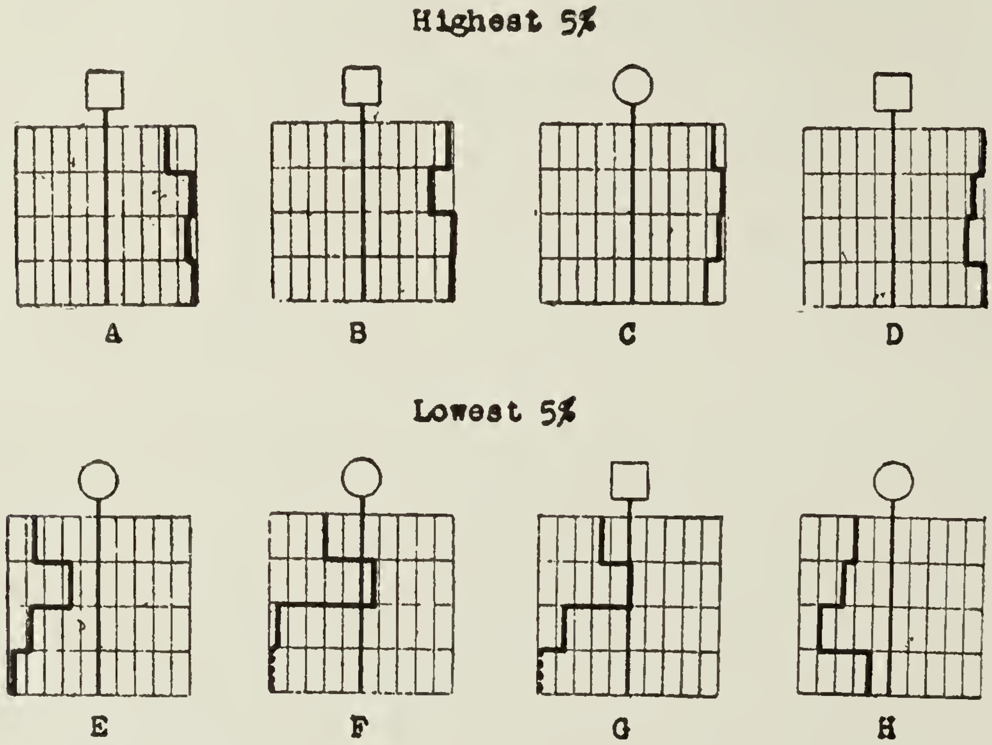

FIG. 8. Highest 5 percent. and lowest 5 percent. talent profiles.

Two of the superior group are brothers and two of the poor group are sisters. Three of the superior group are propositi. All of the poor group were included in the study because they were connected by marriage into the musical families investigated. In the superior group no rank occurs below eighty-six per cent. In the poor group no rank occurs above fifty-eight per cent. In the latter group 'no rank' in memory means that they tried the test but were baffled by it. The pitch thresholds for the superior group extend from 0.4 d.v. to 1.6 d.v., for the poor group from 5.4 d.v. to 9.7 d.v.

The significance of these four capacities for the purpose of identifying experimentally musical ability or lack of musical ability may be realized by a direct comparison of these talent profiles with the supplementary musical data. For this reason the writer is presenting such a comparison in as condensed a form as possible, reporting directly from the individual papers.

I. Musical Environment in the Home During Childhood

Superior talent profile group

1. Very unusual. Mother a musician. Members of family singing and playing together. Many musical friends and professionals brought to the home.

2. Had only the opportunities of a musical family possessing a piano and love for music. Piano, flute, and violin in the home.

3. Very remarkable. Father a concert artist. Mother an amateur singer. Artists came to the home. Piano and violin in home.

4. Reed organ and piano in the home. Mother played the seraphine. Choir rehearsal held in the home. Cello, piano and flute the only instruments.

Poor talent profile group

1. Almost no music heard at home. Hymns sung at morning prayer. Melodeon in home, later a piano.

2. Practically no music in the home. No one played or sang much. Victrola and piano the only instruments.

3. Piano in the home. Sisters played some.

4. Mother played piano in very elementary way.

II. Musical environment in the community during youth

Superior talent profile group

1. Attended city concerts regularly during youth.

2. Opportunities to hear good music in community began with academic college days.

3. Hear city concerts, and splendid music in city church.

4. Heard city music festivals during youth.

Poor talent profile group

1. Very poor opportunity to hear music in the community, nothing except country church music until the age of 13.

2. No report.

3. Heard good church music.

4. During later youth heard good music in cities with tremendous enjoyment.

III. Effort exerted to gain or avoid musical environment

Superior talent profile group

1. Made attempt to get out of musical environment to extent of becoming bored with musical people.

2. No report.

3. Musical environment thrust upon her.

4. No effort exerted to avoid musical environment.

Poor talent profile group

1. No effort made to gain a musical environment.

2. No report.

3. Desired to keep away from music when young.

4. No report.

IV. Musical encouragement in the home

Superior talent profile group

1. Mother principally encouraged music study.
2. Received every encouragement from both parents.
3. Father's pride and interest were incentives for study aided by mother's great sympathy and keen judgment.
4. Excellent encouragement from both parents who expected him to study.

Poor talent profile group

There was no specific report recorded for those of the poor talent group but all of them came from homes where music was not essential and in a few cases no opportunity for study consequently parental encouragement was lacking.

V. Musical education

Superior talent profile group

1. Two years of voice study in the city. Piano study from age 6 until college entrance. Major in music in Eastern University. Harmony, theory, orchestration later.
2. No voice study. 1 year piano and organ. Summer study in theory, harmony, piano, and organ.
3. One year voice study. 10 years piano study; 6 years violin; 2 years study abroad with violin, harmony, counterpoint, orchestration.
4. Four years' voice with two valuable teachers. 10 or 12 years piano with two teachers. Organ study began in early youth and continued 10 years with three very fine teachers. 4 years harmony and composition with three teachers. History of music and theory of church music. One-half year orchestration.

Poor talent profile group

1. No musical education.
2. No musical education.
3. School music 2 years once a week.
4. No voice study. 6 years piano without much results.

VI. Musical activity

Superior talent profile group

1. Recognized composer. Improvises on piano readily. Bass singer 3 years in university glee club. Accompanist for concert singers.
2. Improvises as an expression of thoughts and feelings. Composes hymns and children's songs. Student of folk songs. Musical lecturer. Baritone in quartets. His real instrument is the church organ.
3. Composer of established reputation. Often improvises at piano. Semi-public appearances as director of choruses, as an accompanist. Always able to carry a tune but never sang much.
4. Pipe-organist, church musician. Improvises freely. Written monographs on music. Second bass in quartets, choruses, glee clubs, choirs.

Poor talent profile group

1. Never has sung much but could teach school songs with aid of a pupil. Does not play.

2. Sang solo at school when 6 years old, and that was the last. Does not play any instrument.

3. Could not carry a tune. Made no public appearance in music.

4. Never goes near a piano. Impossible to carry a tune even now.

VII. Earliest activity in music

Superior talent profile group

1. First compositions at age of 12, some in print 6 years later.

2. When a child played baritone horn in brass band. Age 9 led altos in a chorus at musical convention.

3. Began to compose at age of 12, wrote string quartet.

4. Recorded an original melody at age of 6. One year later wrote a piece played by village band. Played church organ since age of 16.

Poor talent profile group

Data reported under musical activity preceding.

VIII. Rôle of music in daily life

Superior talent profile group

1. Music enters into life every day in some way. Playing for self is part of daily diet. Daily relaxation from business.

2. Music daily is a great source of courage, a spiritual tonic. Used as a study rather than for entertainment.

3. No report.

4. Music daily is absolutely paramount.

Poor talent profile group

1. Music not in mind much daily.

2. Many days and no music heard at all.

3. No report.

4. No report.

IX. Desire to have studied or heard good music

Superior talent profile group

1. Desire to study took him abroad.

2. Always desired to play and sing. Never a distressing desire to hear good music unfulfilled. Goes to concerts rarely.

3. Experienced great hunger one winter when voluntarily giving up symphonies.

4. If he cannot attend a concert he sits down and thinks it out.

Poor talent profile group

1. Wanted to study at age of sixteen but could not. Never puts herself out to attend concerts.

2. Always wished she had studied music. Has longed to hear special singers when she could not.

3. Desired to keep away from music when young.
b. No desire to study music. When lonely would like to go to a concert.

X. Memory and Imagination

Superior talent profile group

1. Memory is note association. Pieces he knew at age of twelve are "in his fingers now." Forgets memorized selections unless playing them constantly. Creative imagination evidenced in compositions.
2. Auditory imagery most important in memory. Touch in finger tips helps. Visualization of keyboard great help in playing from memory. Always hearing music when awake. Improvisations and compositions indicate creative imagination.
3. Sits away from piano in trying to memorize and tries to get it in her eyes. If retained it will be visual. Often recalls things with hands that cannot be seen with eyes. When composing things heard in "mind's ear" before hearing them on piano.
4. Very easy to memorize. Wholly auditory. Neither notation nor keyboard helps. Always something musical going on in his mind. Mental hearing comes first in all musical processes. Purely creative in all his work.

Poor talent profile group

Those in this group have no experience in memorizing music.

1. Thought and rhythm easier to remember than words. "I see rather than hear." Could sing in her mind and not in her voice.
2. Takes a long time to memorize. Always sees words on a page. Can remember words more easily by writing them down.
3. Remembers things that interest him. Never sees a printed word in memory. Music often brings past thoughts to mind.
4. Creative imagination exercised with color rather than sound.

XI. Evidences of manual skill

Superior talent profile group

1. Not especially adept in mechanics.
2. Hates tools, no mechanical skill. Sketches with pen and ink.
3. Facility in turning things out in carpentry and sewing.
4. Apparent skill and good eye in occupations of hand. Uses tools and pencil with accuracy.

Poor talent profile group

1. Does manual tasks easily.
2. Skillful at sewing, lace and jewelry making.
3. "Mechanical skill inherited from grandfather."
4. No report.

XII. Attitude toward mathematics

Superior talent profile group

1. Liked mathematics in a pictorial way.
2. Mathematics perfectly easy.

3. Absolutely no interest in mathematics. Had no mathematical gift.
4. Geometry interested especially.

Poor talent profile group

1. Natural aptitude for mathematics.
2. Mathematics very difficult. Detests it.
3. No report.
4. Liked mathematics very well.

XIII. Interest in other arts

Superior talent profile group

1. Promotion of arts. Constantly searching in poetry. An untrained eye for color. Dancing never a necessary pleasure.

2. Cares for music of poetry. No interest in dancing, sense of rhythm not physical.

3. Loves the sounds in poems. Enjoys dancing very little.

4. Poetry not a necessary pleasure. Very little interest in dancing. Form of paintings interest but color means little. Loves to follow form in architecture.

Poor talent profile group

1. Recreation and inspiration in poetry. Longs some to dance, likes the activity of it. Longed to work with color and form in painting, passionately fond of it.

2. Great lover of poetry. Some interest in dancing, finds it hard to do. Interest in ceramics.

3. Appreciates poetry now more than ever. Not interested in the dance, poor on time.

4. Fond of poetry. Reads it some. Very fond of all kinds of dancing. Sculptures in her fancy. Scenic decorator. Amateur acting.

Summary of supplementary factors for the two contrasted groups of talent profiles. The highest 5% and the lowest 5% of talent profiles represent the greatest extremes obtained in this preliminary investigation. There are four individuals in each group.

The age span for both groups varies from 40 years to 65 years.

The musical capacities for the superior group show a variation in rank for pitch from 86 to 99, for intensity from 87 to 100, for time 90 to 100, for memory from 91 to 100; for the poor group the pitch ranks vary from 14 to 36, the intensity ranks from 25 to 58, the time ranks from 6 to 16, the memory ranks from 2 to 39, with two of the group who tried the test but could not handle it.

Two of the superior group had superior musical environment in the home during childhood. All of the poor group had very little or no musical environment in the home during childhood.

Perhaps all heard music in the community during youth but those of the poor group and one of superior group heard little or none until their later youth when moving to a city or entering college. The others were taken to city concerts while still remaining at the parental home.

In general these of the superior group were born into a musical environment and made little or no effort to get away from it. Those of the poor group heard little or no music and made no effort to gain a musical environment.

Those of the superior group received every encouragement for study while those of the poor group received little or none.

Three of the superior group received a superior musical education, one an average musical education. The poor group had practically no musical education.

In musical activity the two groups are extremely contrasted. Indeed we might say that the superior group are representative of the most musical persons, the poor groups the most unmusical.

Music in some form is quite essential daily for the superior group but not a daily occurrence for the poor group.

Creative ability in music is exhibited by every member in the superior group, but by none of the poor group.

General Summary

1. Four of the Seashore Measures of Musical Talent were given to eighty-five members of six unrelated family groups in which one member of a family group was conspicuously known as talented in music.

2. These measures were supplemented by a systematic interrogation which covered questions in regard to musical environment, musical education and training, musical activity, musical appreciation, musical memory and imagination.

3. The responses to all the supplementary topics for which there was adequate material were classified into three sections: A, C, E.

4. The relation between the results in the measurement of musical capacities and the ratings of supplementary topics, is shown by means of frequency tables.

5. The family records are presented, in pedigree charts, comprising 531 individuals, in tables of individual ranks and ratings in the measures and supplementary data respectively, and family musical history, followed by an explanation of the form of preparing the reports for filing in the Eugenics Record Office, Cold Spring Harbor, Long Island, New York.

6. A study was made from the family musical history in regard to the tendency of children to be musical or non-musical according to their parentage and ancestry. Three out of ten possible types were represented by the available data.

7. The result of each measurement of musical capacity was evaluated in terms of rank based on norms established for unselected groups.

8. The talent pedigree charts are a graphic presentation of the individual talent profile for each family. By means of these charts and by tables showing the relation between children and parents in each capacity, certain statements are formulated regarding the type of offspring resulting from the represented six types of possible matings.

9. The harmony of the results with certain Mendelian laws in the family distribution tables of assumed gametic formulae is not improbable.

10. In a study of age groups suggestions are proposed in an effort to eliminate or diminish some of the recognized sources of error.

11. The significance of this technique in identifying those who are musical and non-musical is partially shown in a comparison of the lowest five per cent. and highest five per cent. talent profiles for which a separate summary is given.

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VOICE INFLECTION IN SPEECH

By Glenn N. Merry, Ph.D.

The disc lever recorder; the cylinder lever recorder; the phonograph recorder with the tonoscope; character representation of readings—samples from E. H. Sothern, Rabbi Wise, Franklin D. Roosevelt, Mrs. Corrine Roosevelt-Robinson, Julia Marlowe, James W. Gerard, and William G. McAdoo.

The purpose of this investigation was to develop a method for determining objectively the pitch of the human voice, in any or all of its inflections in speech. From this work certain preliminary conclusions were drawn as to tendencies or laws of pitch inflection in speech. In the present article, we shall, however, limit ourselves to the mere presentation of methods, of measuring, recording, and interpreting the objective records. As this technique furnishes a convenient tool in the study of pitch of speech, it may be used for countless purposes in the scientific approach to this problem.

The disc lever recorder

What form of instrument should be employed in the recording of speech will depend largely upon the problem in mind. Wherever the object is to study vowel quality, or any other form of timbre, the most refined and elaborate methods yet available can scarcely be said to be adequate. For the present purpose, however, we are limited to a study of fundamental pitch only; this fact simplified the requirements of apparatus. After a survey of the various types of optical, graphic, photographic, and microscopic methods of measuring the pitch of the voice directly as spoken or as taken from phonograph records, we finally devised a comparatively simple form of recording apparatus somewhat analogous to Scripture's simple lever apparatus (1).[1]

[1] While much direct study of the living voice was made under various circumstances, the experiments here reported were all made with standard phonograph records of speeches because these records had been made without knowledge of the fact that they were to be studied and may, therefore,

This apparatus is constructed on the principle of the pantograph with a single direct lever which enlarges the amplitude and shortens the wave relatively for convenience in reading. The model here used was assembled mainly from standard pieces of apparatus in the laboratory as is shown in Figure 1, a and b.[2]

In Figure 1, a (beginning at the left) note in order the driving motor, the kymograph drum, the recording lever, the Cattell speed reducer, the microscope for centering the disc, the rheostat, the revolving phonograph table, the hand-controlled wheel on the endless screw, the induction coil, and (above) the electric lamp for illuminating the apparatus.

Figure 1, b presents a closer view showing (from right to left) the teeth of the phonograph turn table, the pulley for the drive, the mercury cup for a mercury contact with the teeth, the endless screw of the mount, the bearing support of the lever, the speed reducer, and the drum.

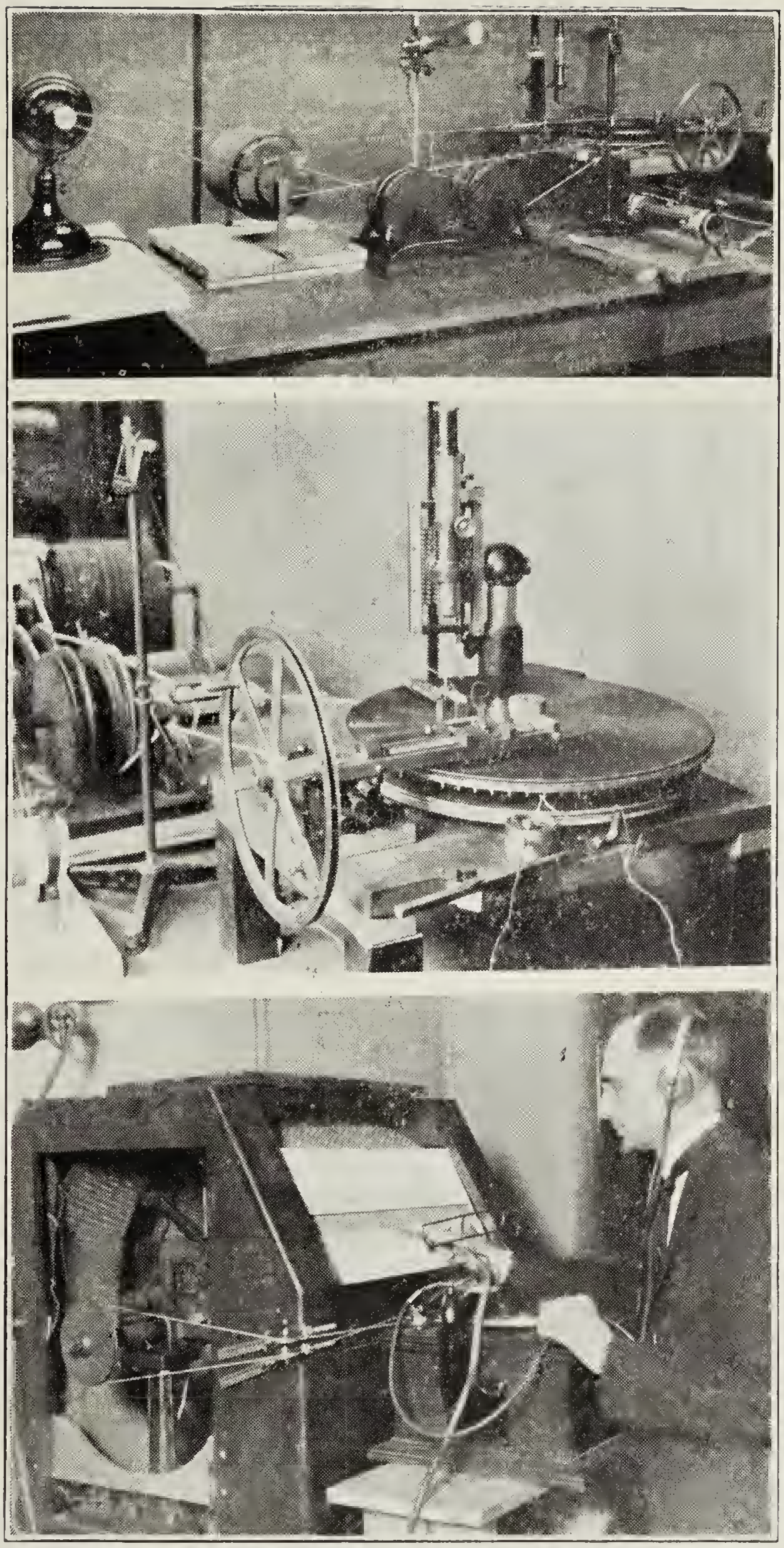
An ordinary phonograph plate was mounted accurately on an upright pivot with belt wheel on the same axis, below. The top of the pivot was threaded and the record was securely fastened in place with a thumb nut. The record could, therefore, be revolved at any desired speed as controlled through the speed reducer driven by the motor.

A very rigidly and accurately built endless screw was so mounted that, by turning the crank wheel at its one end, a carrier for the support of the lever could be moved with precision for any desired placement between the periphery and the center of the record and thus set or keep the recording needle in any desired groove.

Strange to say, the phonograph records are not very accurately centered. The central pivot was, therefore, made a trifle small and whenever a record was to be mounted it was accurately centered by means of the reading microscope through which a

be regarded as representative. Furthermore, they are available in permanent form for comparison and verification. Columbia and Victor records were used. However any disc record with the lateral wave would serve just as well.

[2] The various forms of apparatus here described were designed in cooperation with Professor Seashore.



a

b

c

Fig. 1 —a. View of the disc lever recorder. b. Closer view of same showing timing device. c. View showing adaptation of Seashore tonoscope for disc records.

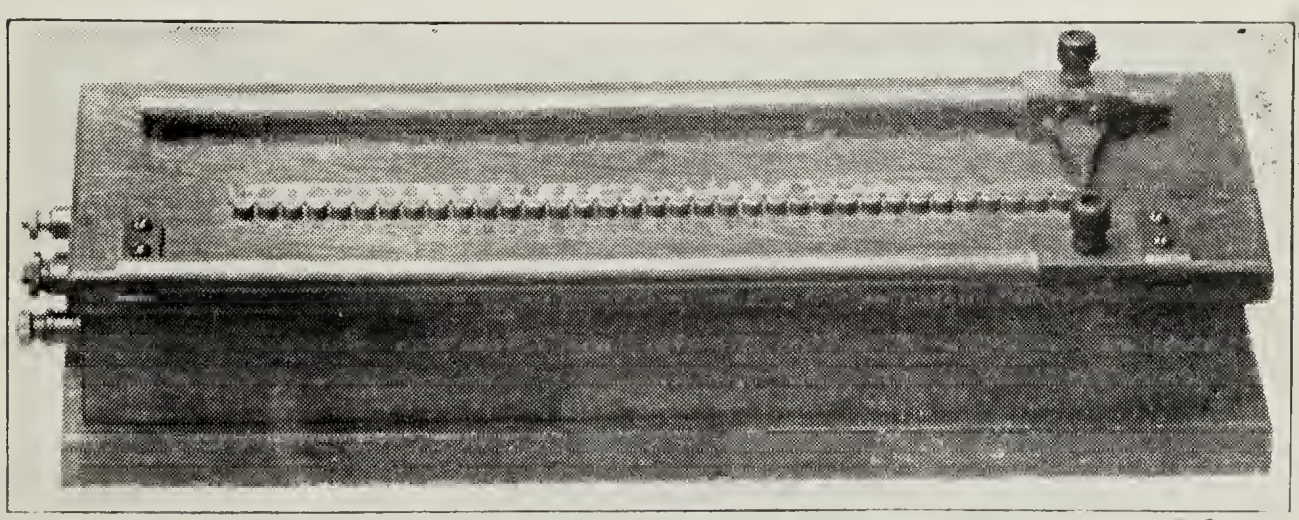


Fig. A. The musical touch audiometer.

(Figure for article p. 261)

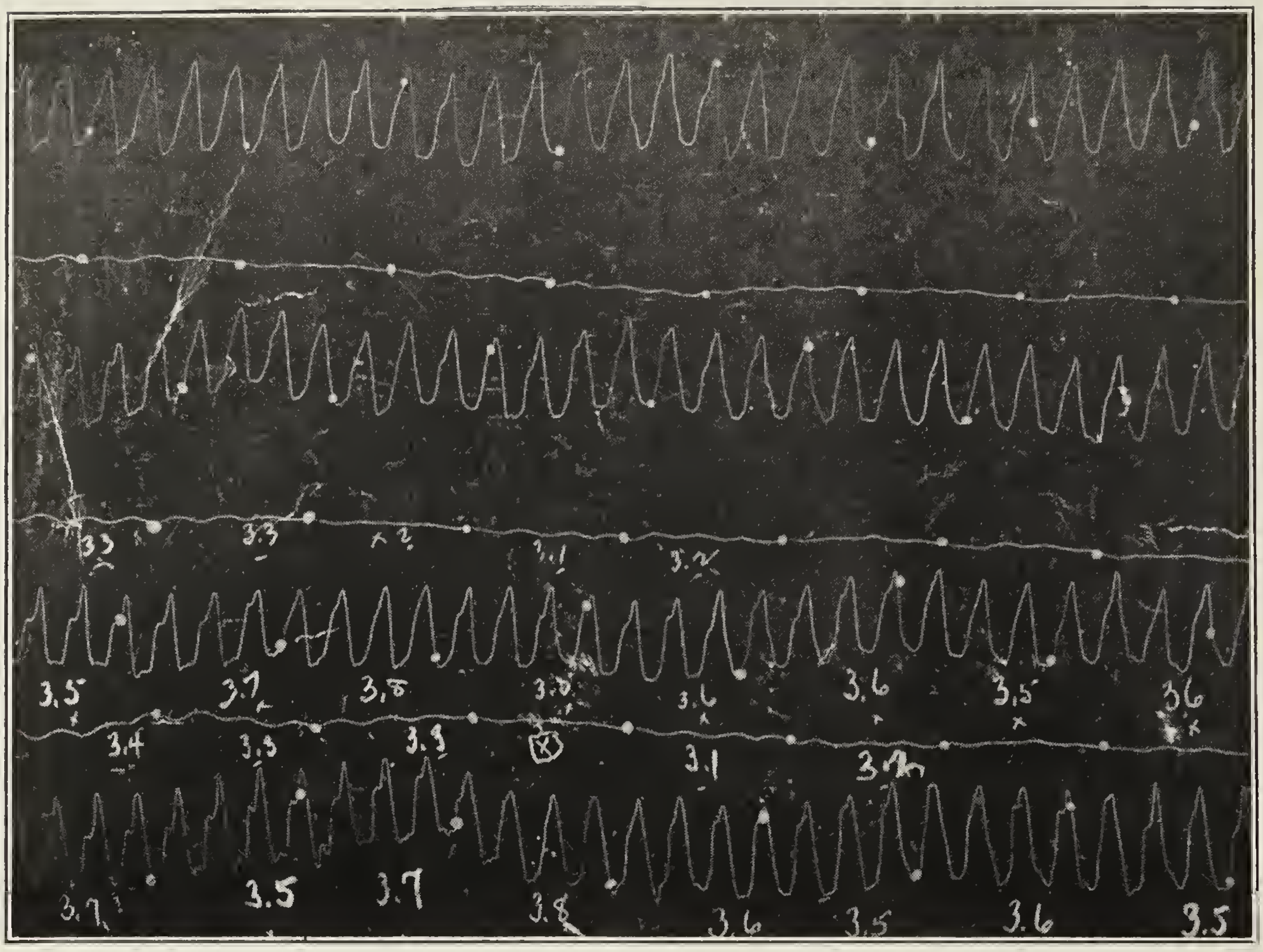


FIG. 2. A section from a record of a relatively pure tone (actual size.)

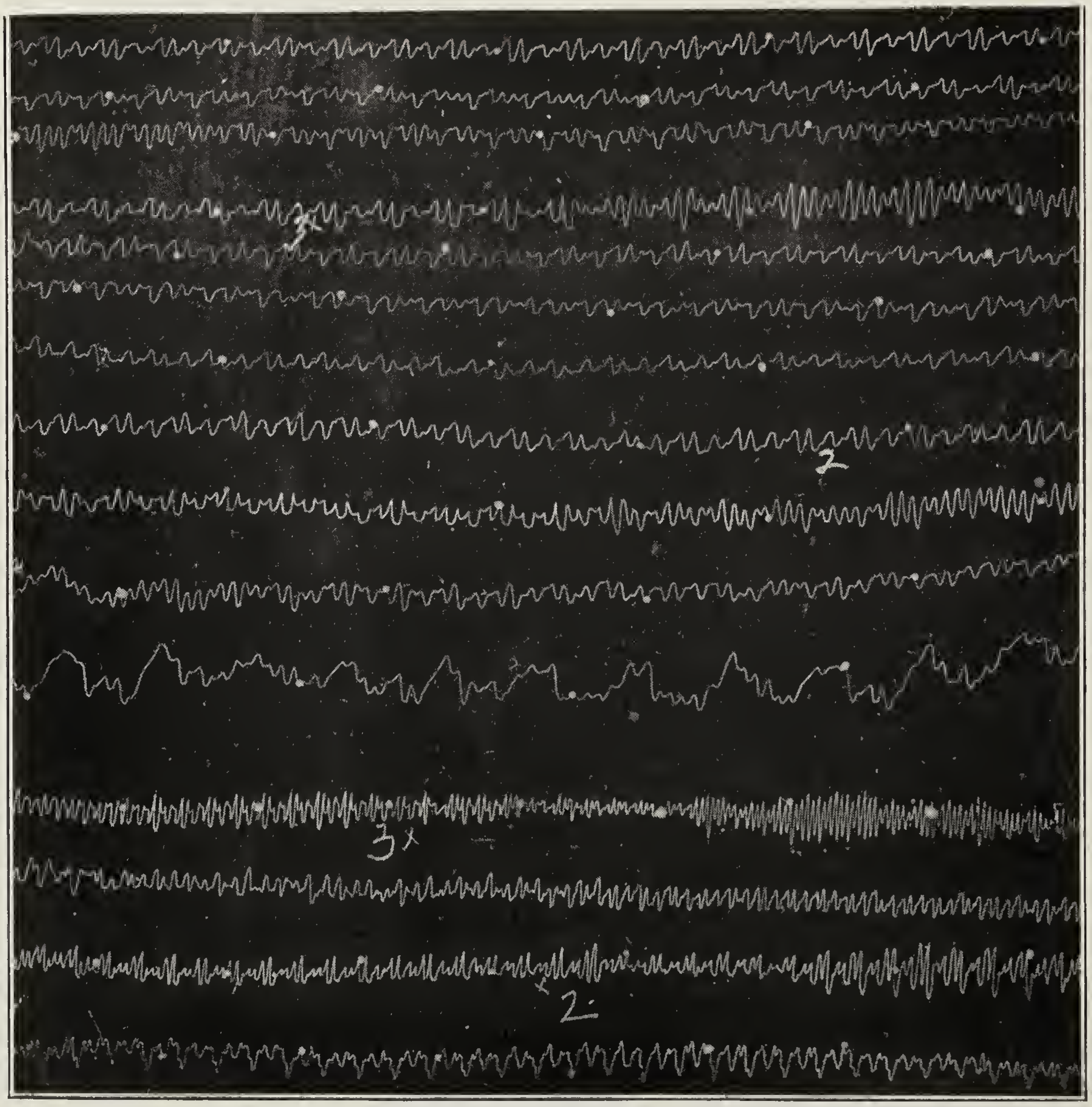


FIG. 3. Section of a speech record showing differences in wave-form.

given groove might be observed under the hairline for a complete revolution. Thus centered, the disc was fixed in place by means of the thumb nut.

After experimenting with levers of aluminum, glass, bamboo, ribbed steel, wire skeleton, and others, a lever made from black walnut was finally adopted. It measures 890 mm. from fulcrum to tip and 4.2 mm. from fulcrum (writing point) to bearing support. This, therefore, enlarges the amplitude about 212 times, which is perhaps more than is really necessary. A lever 500 mm. long would answer most purposes. The long arm of the lever was made tapering and three-ribbed, in cross section like an inverted T (⊥) and weighed 34.71 grams. The needle point extended backward like a (V), of which each prong was delicately mounted on a fine needle cross bar in a horizontal position on the end of a wooden lever. This arrangement gave lateral rigidity to the writing-point and permitted the needle to rest by its own weight upon the drum, thus allowing for slight up and down movement of the lever.

The needle at the fulcrum was rigidly supported at the same angle that the needle ordinarily traced in the phonograph reproducer. The "Sonora" silver needles were found most satisfactory. Smoked paper for the tracing was carried on an ordinary Zimmerman kymograph drum 16 cm. in diameter and 11 cm. wide mounted on a firm support and supplied with pulleys for different speeds. The form was free to slide laterally the width of the paper as on the kymograph. To synchronize the speed in any given ratio, determined by the relative diameters of the belt wheels on the phonograph turn table and the drum, the belts for the turn table and the drum were taken off from the same wheel of the speed reducer.

The principal new feature in this apparatus is the timing device. It was necessary to get into the graphic tracing some exact measures of the rate of vibration. To accomplish this, 77 teeth were cut in the phlange on the under surface of the phonograph plate, or revolving table; each tooth space was therefore equal to the distance the phonograph record would pass under the needle in the groove in .01 sec., if the record had been recorded at 78 revolutions per minute which is the standard rate. Under these teeth a delicate spring tip was mounted over a mercury cup in such a way that, for every time a tooth passed, this spring would fly back and thus break its mercury contact. This mercury contact was in the primary circuit of an induction coil for which the secondary circuit was completed through the lever and the base of the drum. Thus, every time the mercury contact was broken, a spark would fly through the tracing point making a round dot in the record. On the conditions stated, these sparks would then be exactly .01 sec. apart, thus furnishing a time unit of measurement, since the speed of both the drum and the phonograph turn table was controlled from the same source.

Variety in speed was readily obtained since the motor had a three-speed switch, the drum had two sizes of pulley, and the current in the motor could be varied with the rheostat. The most favorable speed of recording varied with the prevailing pitch. When the waves were all relatively pure, or without intricate contour, a favorable rate was found to be about one revolution per minute of the phonograph disc. But when the waves were of large amplitude or filled with many partials, a slower speed was necessary. In general, the principle followed was that, in the interest of economy, the record speed should be the fastest rate in which the momentum of the mass of the lever would not be disturbing.

In order to place or replace the needle in a particular groove a chalk line was drawn on one or more radii of the disc in such a way that when the needle passed through a given groove it "plowed out" the chalk and it was easy to locate the needle in the desired groove by means of a hand reading glass. If a particular word was desired in any part of the record, talcum powder was sifted in a thin layer on the record before playing it in the usual way, except for reduced speed. The moment the desired word was reached, as judged by hearing, the record was removed and then placed upon the graph apparatus. The desired groove could be located in the same manner as with the chalk.

In all forms of graphic, photographic, or microscopic determination of pitch, we strike a natural limit of accuracy in that if we count the number of waves in a relatively long unit, such as 1 sec., 5 sec., or 25 sec., we take no account of fluctuations within that period. On the other hand, if we have a short segment as in this case, .01 sec., covering, *e.g.*, from 1 to 10 waves, and multiply the reading in this unit by 100, in order to reduce it to "number of vibrations per second," we magnify the error of reading.

A sample tracing, actual size, is shown in Figure 2, in which the method of counting is illustrated in the lower part of the record. The number of waves are counted for each .01 sec., the waves being read in tenths. The reading is therefore reduced to number of vibrations per second by removing the decimal point two places to the right. In order to minimize the error in estimating tenths, the record is made cumulative. Thus, if the spark at the beginning of the .01 sec. unit is at a crest and the one at the end is judged to be 3.7 of a wave further on, then this fixes the fact that .3 of the broken wave shall be counted to the next unit. When carried in this way the error of reading for a segment of *e.g.*, .1 sec. becomes negligible. This then gives us a record in two forms: first, a record for each .01 sec., subject to a considerable error in reading, and, second, a record for any cumulative period of units which is a correct average time without detail as to internal fluctuations.

In order to test the accuracy of reading pitch in hundredths of a second, the record was made of the tuning fork tone in the pitch record of the Seashore Measures of Musical Talent (2). It was found that the record for one second is accurate to within a fraction of a vibration; but when we take a segment of any given hundredth of a second in that record it is subject to an error of about 10%. Therefore, when pitch at a given moment of the spoken word is indicated, it is subject to an error of ± 10% of the vibration frequency for a single wave; 1% for a group of ten waves; or 0.1% for a group of one hundred waves. By reading in units of 1/100th wave length, under a measuring microscope, greater accuracy can, of course, be secured. But this was deemed unnecessary.

For the purpose of tracing the detailed pitch inflection of spoken words, it is of course necessary to use this short time unit. In music such an error would be serious, but in speech the pitch of the voice varies through so wide a range in almost every word that a difference of this magnitude is relatively unimportant.

The sensitiveness of this apparatus to wave form may be illustrated roughly by a series of samples of records shown in Figure 3. The wave may be so complex that it is often extremely difficult to know what constitutes a wave unit as in Figure 3a, in which the partials are very strong. In general, this lever graph transcribes whatever is in wave form on the phonograph record, that is, the vocal elements of speech.

The cylinder lever recorder

The apparatus described above is restricted to permanent records of the lateral wave form. There are, however, two other situations which we have to meet: first, the adapting of the apparatus for the recording of the vertical, or "hill and vale" type of wave, as in the cylinder machines and, second, the prevention of injury to records of this type.

The apparatus for this purpose was constructed on the same principles as for the disk lever graph with one fundamental exception. To reduce the bearing or strain at the fulcrum, the recording lever was mounted in a vertical position with just enough of the lateral slant to give the needle the desired pressure in the groove. As the needle in these records moves up and down instead of sidewise, the tracing point was adjusted for this direction of movement. A lever of 500 mm. was found to amplify adequately. For future work this form of the apparatus will perhaps be the more important because it enables one to make a dictaphone record of the voice under any desired conditions and study it immediately. It also commends itself because practically all scientific and artistic records made for historical or experimental purposes are in this form on soft cylinders.

This cylinder lever apparatus was improvised in the same manner as the disc lever apparatus, but both can be put in more compact and economic form by being especially constructed in a permanent and compact unit, now that preliminary tests have been made. This will involve certain fine adjustments for the movements of the drum, and other parts which we have not provided for in the present form. The main thing to be considered is that we have here now a transcribing apparatus which records pitch faithfully from the soft record and does not injure the record any more than an ordinary playing injures it. Records of Indian music, *e.g.*, may thus be put into indestructible, readable, and measurable form while the original soft wax record is in a good state of preservation.

The phonograph recorder with the tonoscope

Several years ago Seashore demonstrated that the tonoscope will record from the phonograph just as well as from the living voice. It is, therefore, possible to do all the forms of conventional pitch reading on the tonoscope (3) from a phonograph record.

The adjustment of the disc type of record with the tonoscope is shown in Figure 1c. A pulley placed on the end of the main shaft of the tonoscope connects with a belt running over a pulley on the phonograph pulley on the same principle as in Figure 1a and b. The motor of the phonograph being disconnected, the phonograph disc is driven in exact synchronism with the tonoscope by means of this belt arrangement. By varying the size of the pulley on the tonoscope shaft any desired speed of the record disc may be obtained. It is particularly desirable to use slow speed in order that the detail of the record may be observed with more leisure and exactness. The ordinary reproducer is converted into a manometric capsule by making a gas chamber with intake and jet nipple over the membrane of the reproducer in such a way that the vibration of this membrane will produce the same stroboscopic effect as does the singing into the manometric capsule in the ordinary use of the tonoscope.

In very slow reproduction the tone is so low that it cannot be heard with accuracy from the ordinary resonating chamber of the phonograph. Therefore a small capsule is drawn over the back side of the reproducer connected through a rubber tube with the ordinary binaurals. This conducts the sound well to the experimenter so that he can coördinate the visual readings of the tone with what he hears.

The tonoscopic method of measure and analysis is of very great value in connection with the graphic methods. In many instances the graphic record is so complicated that it is difficult to distinguish fundamental from partials; but, in the slow reading of the record on the tonoscope, one can see in the moving picture on the screen the exact movement of pitch and compare the record of this with the graphic record. This is particularly true of pitch glides where one can see the continuous glide over an octave or more at a leisurely rate. Indeed the tonoscope method is so immediate and convenient and, for many purposes, fully as accurate as the graphic method, that it can be employed to great advantage. The main difficulty is that the time element of the tone can often not be determined with such precision as is needed in the study of speech inflections.

The cylinder type of phonograph was rigged up in the same manner and on the same principle as that just described, and was found to be particularly convenient where an inflection in question was studied under controlled and repeatable conditions. Thus, the observer may be instructed to attempt a given speech effect as regards speech inflection. The speech is then recorded on the dictaphone, and that makes it possible to graph the record and to project it on the tonoscope as often as desired, knowing that it was the same effect that was being studied. After certain fundamental facts have been established by the graphic method the tonoscope method may be used entirely in the study of such dictaphone records made under laboratory conditions.

Graphic representation of readings

Various methods have been employed in attempting to represent pitch changes in speech. If we represent the data in terms of vibrations only, the facts as experienced will be relatively distorted because a small number of vibrations at a low pitch may mean as much in tonal perception as a large number at a higher pitch. The musical staff furnishes the truest proportions of pitch changes at all pitch levels. We have, therefore, adopted the plan of making all graphs on paper in units of semi-tones, designating in the margin the vibration frequency for each semi-tone.

A scale converting vibration frequency into a unit of tenths of a tone for all pitch levels, once drawn, furnishes a convenient means of transferring the reading from vibrations into semitones. The graph, therefore, shows pitch in the vertical units and time in the horizontal units. Each block horizontally represents 1 sec.; there are, therefore, ten observation points within each such unit.

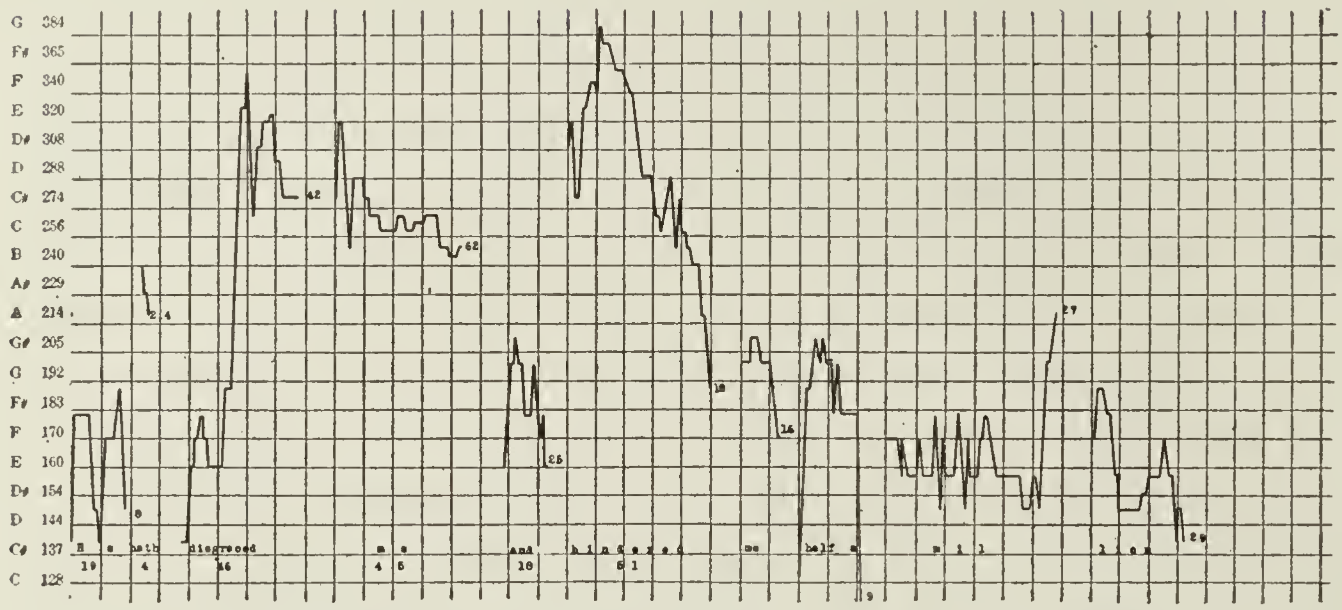
The question then arises as to the advisability of representing the results in the raw plotting from actual readings or in a smoothed curve. The raw readings in terms of tenths of a vibration when converted into a semi-tone, present comparatively coarse contour on account of the fact that the reading is in so fine, units .01 sec.[3]

We have, however, deemed it advisable to plot the curves in raw, as actually read. In studying the curves one should, therefore, bear in mind that the true contour of a curve would perhaps be more nearly right if it were smoothed in accordance with conventional methods of smoothing. The merit of the method adopted is that it shows the actual, individual readings and enables any interpreter or future experimenter to decide what type of smoothing should take place. This is a matter of very great importance for the understanding of the character of pitch inflection and, as the apparatus for determining it in very fine detail is now at hand, we hope to settle this question by experiment at an early date.

In order to illustrate the method, certain typical records are presented in Figs. 4-41. These figures, it will be seen, have the merit of showing the course of the pitch in detail in both accurate and easily interpreted terms, as the pitch is indicated both in terms of vibration and in terms of semi-tones as designated by the notation in the margin at the left.

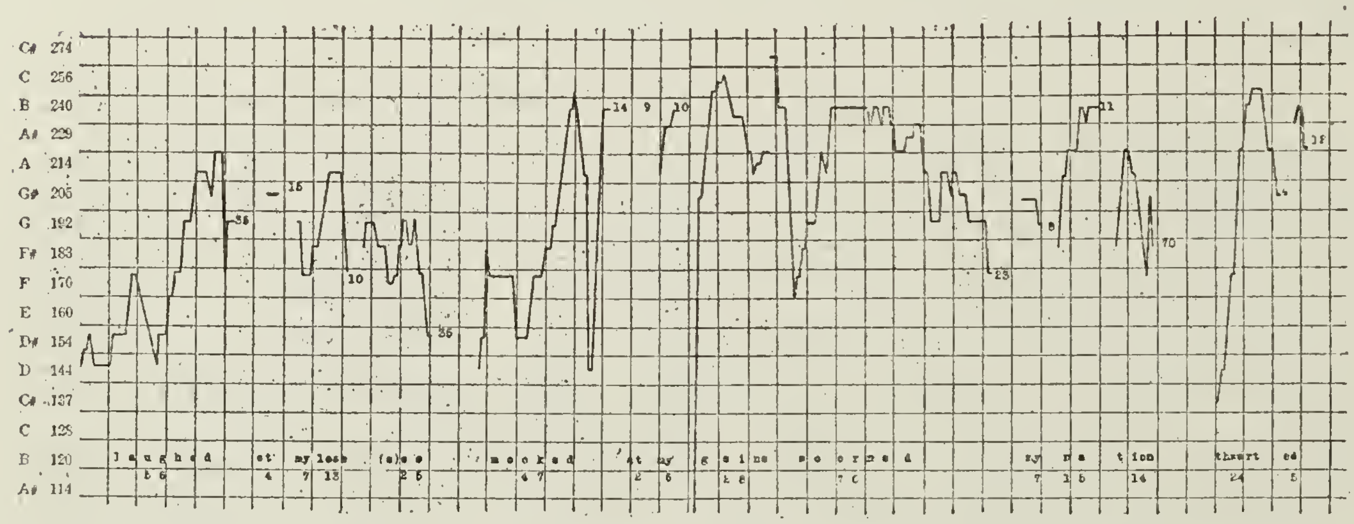
[3] If any emergency should arise in which a higher degree of accuracy in reading should be needed, it is only necessary to run the kymograph drum so much faster that each wave will be drawn out long enough to be read in finer units, possibly one-hundredth of a vibration.

Graphs Series A, Figs. 4-19. Speaker: E. H. Sothern. Shylock's Speech, Victor record No. 74673



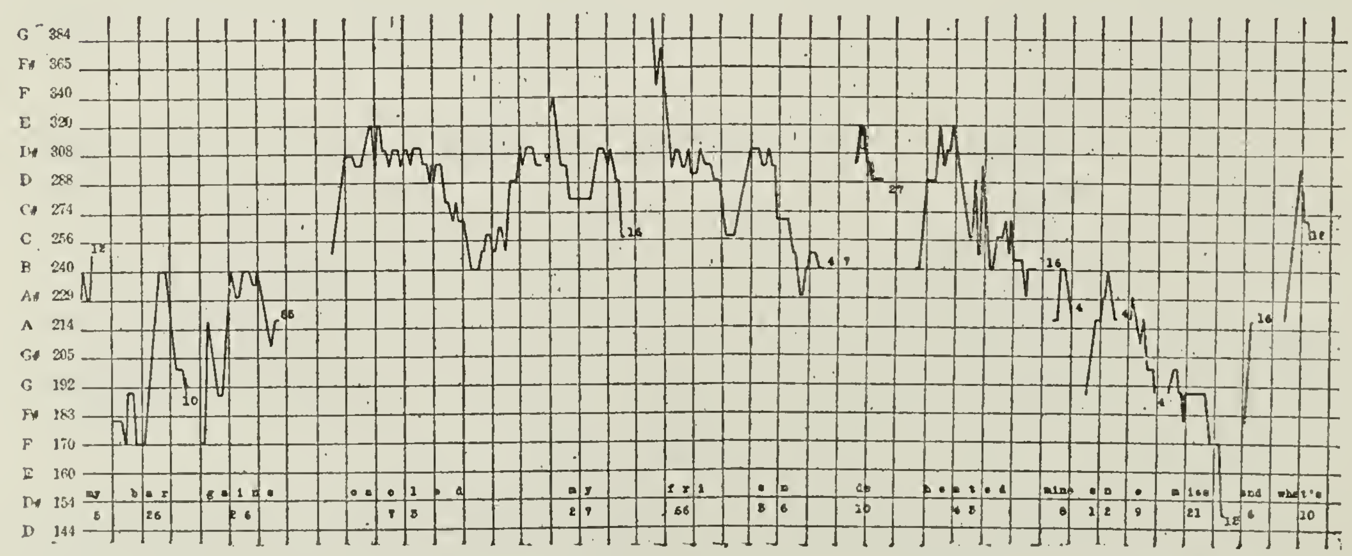
He hath disgraced me and hindered me half a million,

FIG. 4.



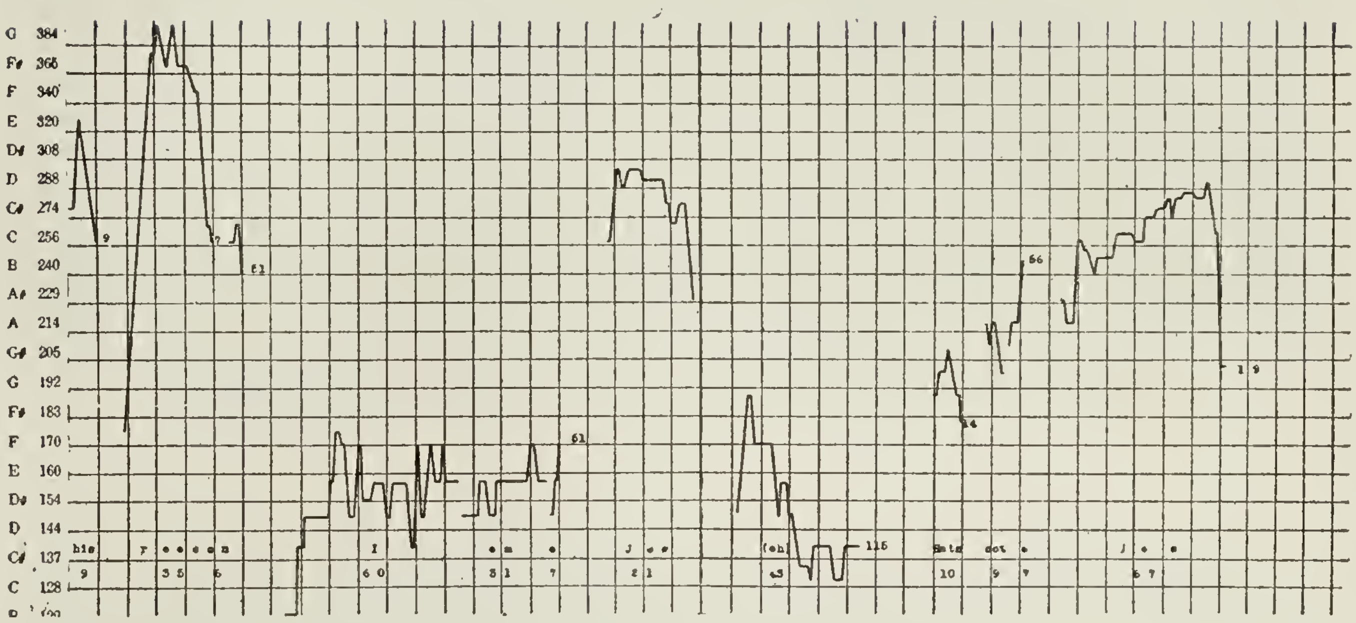
laughed at my losses, mocked at my gains, scorned my nation, thwarted

FIG. 5.



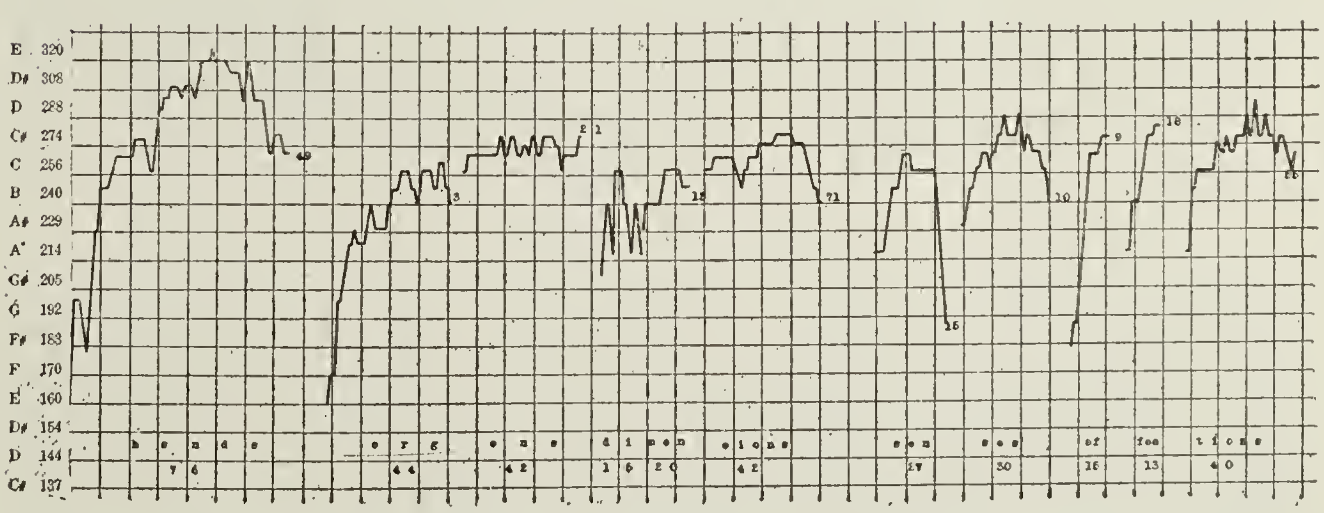
my bargains, cooled my friends, heated mine enemies. And what's

FIG. 6.



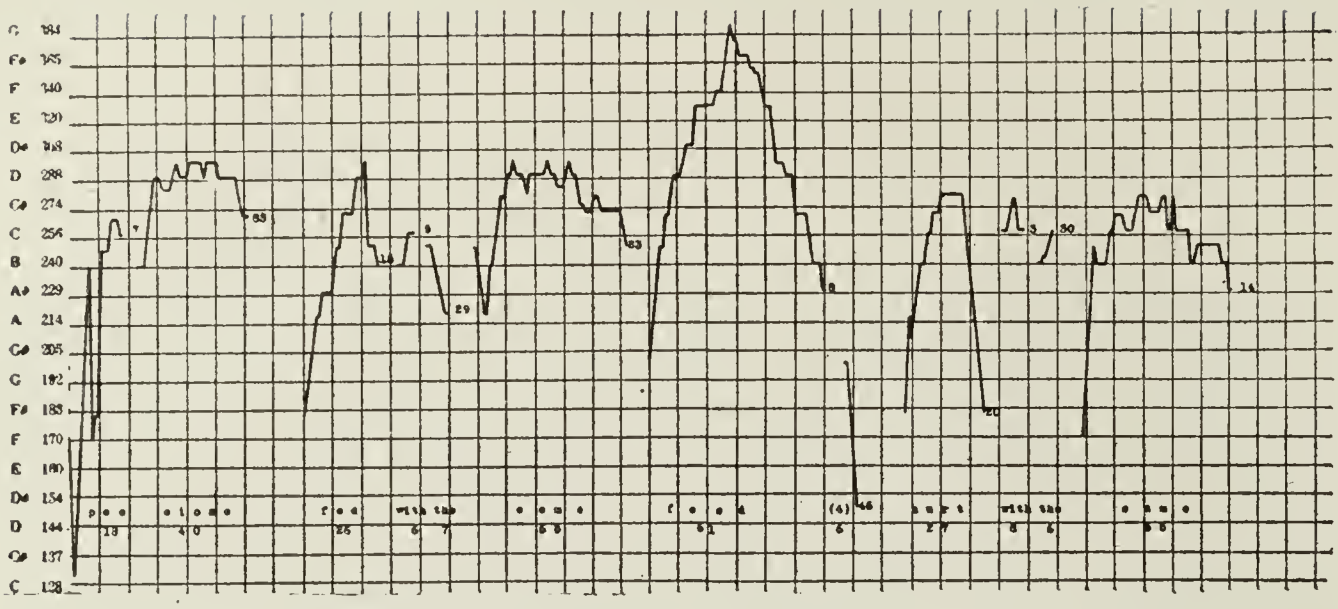
his reason? I am a Jew. Hath not a Jew . . .

FIG. 7.



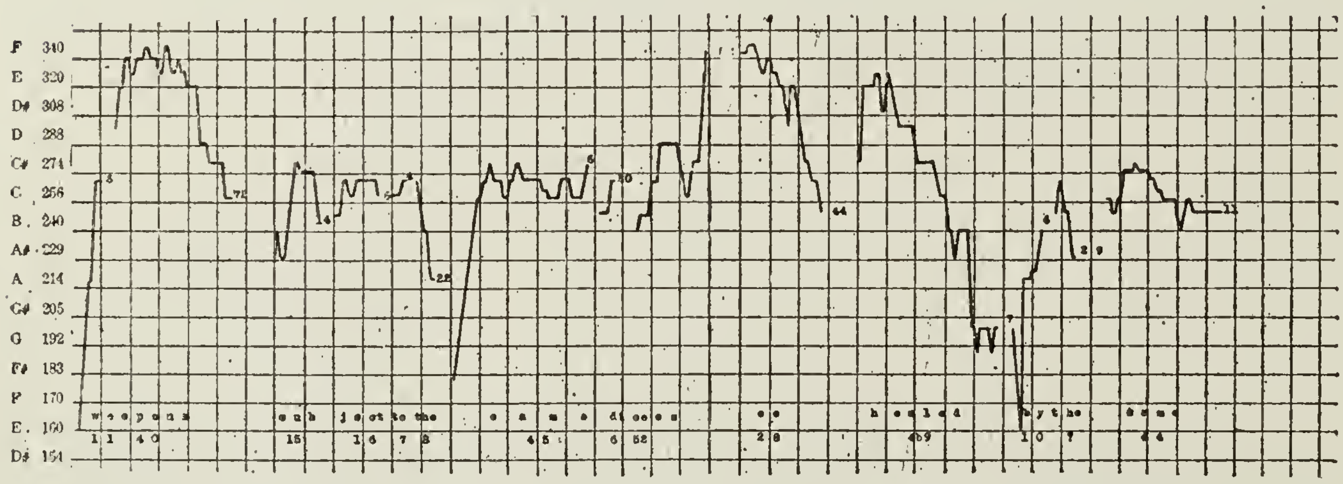
hands, organs, dimensions, senses, affections

FIG. 8.



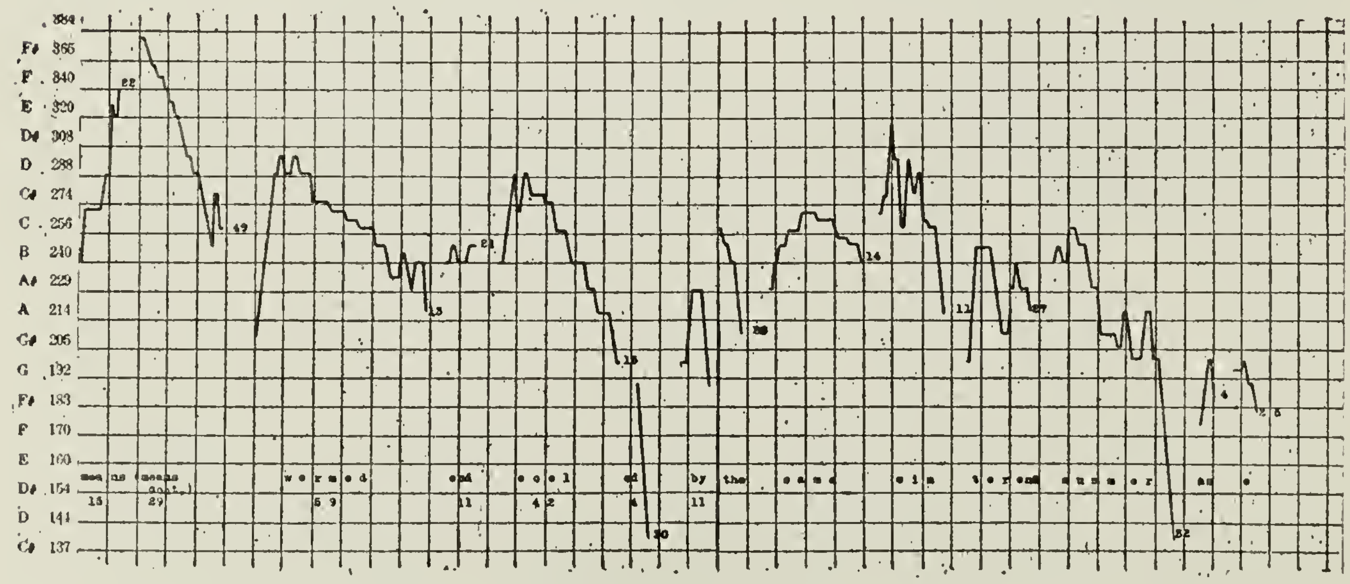
passions fed with the same food, hurt with the same

FIG. 9.



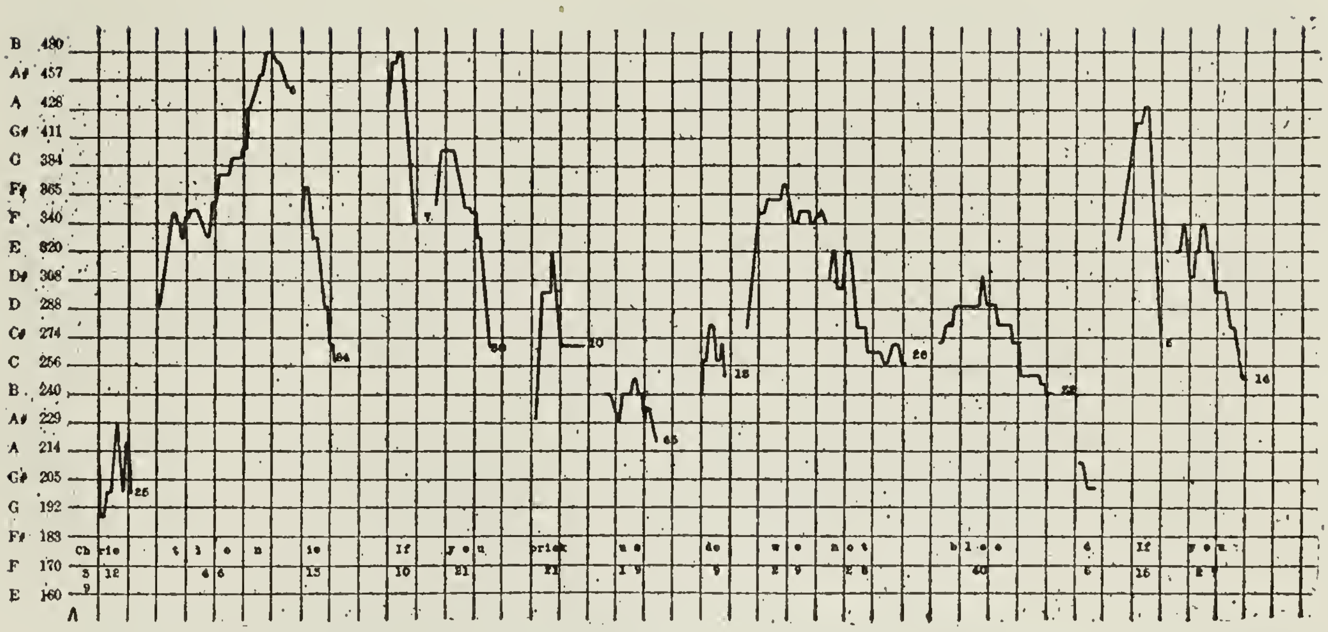
weapons, subject to the same diseases, healed by the same

FIG. 10.



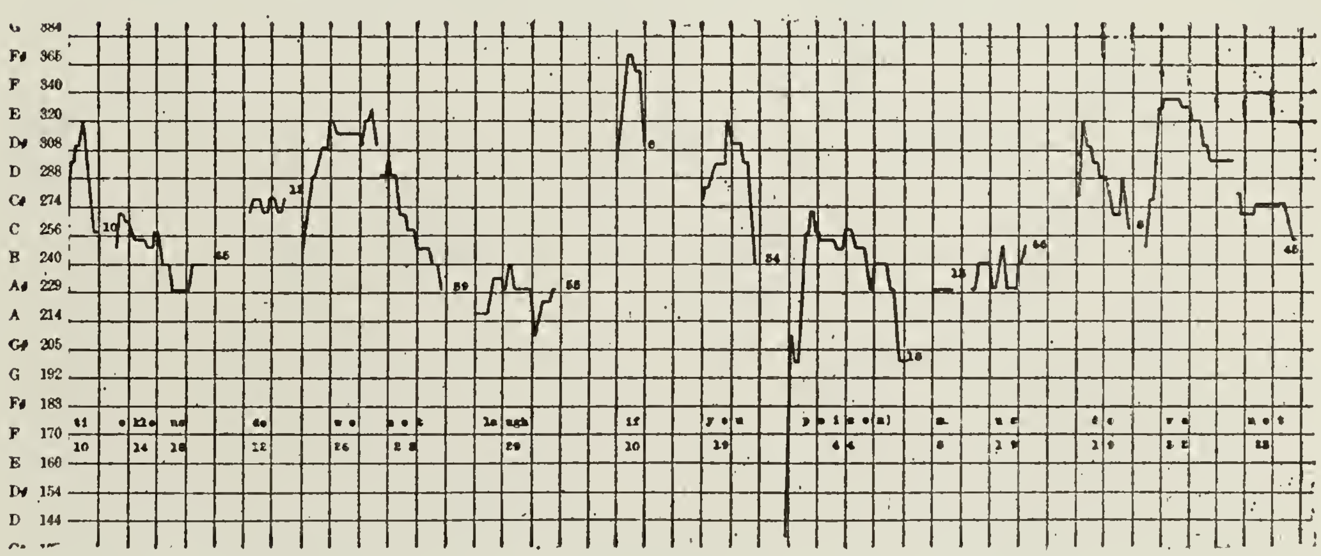
means, warmed and cooled by the same winter and summer as a

FIG. 11.



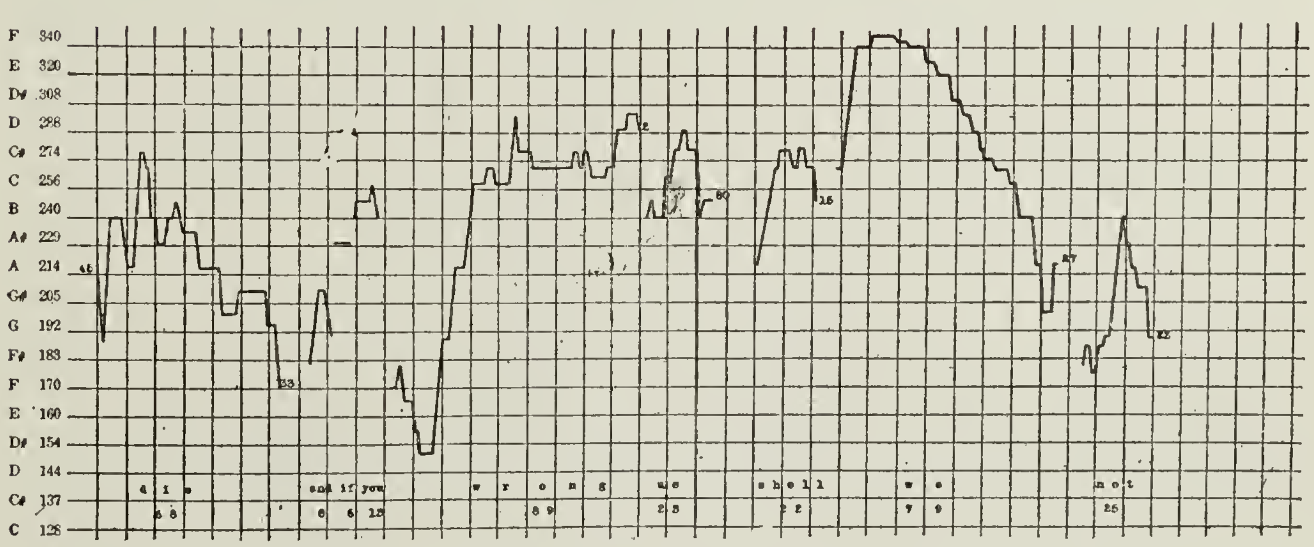
Christian is? If you prick us, do we not bleed? If you

FIG. 12.



tickle us, do we not laugh? If you poison us, do we not

FIG. 13.

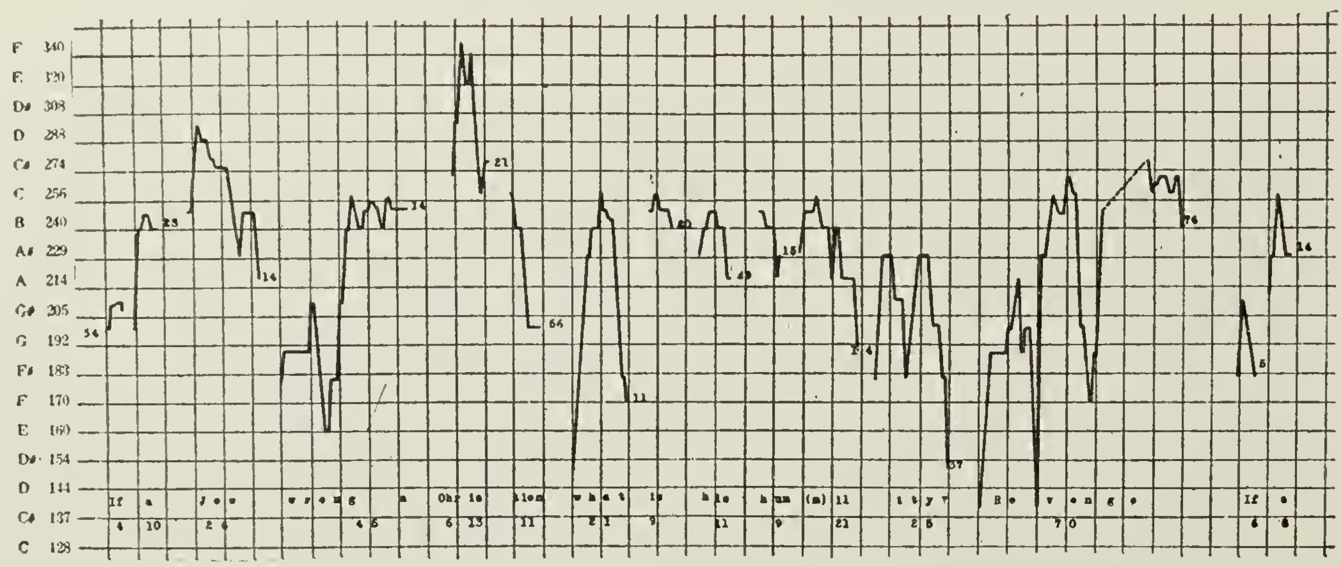


die? And, if you wrong us, shall we not

FIG. 14.

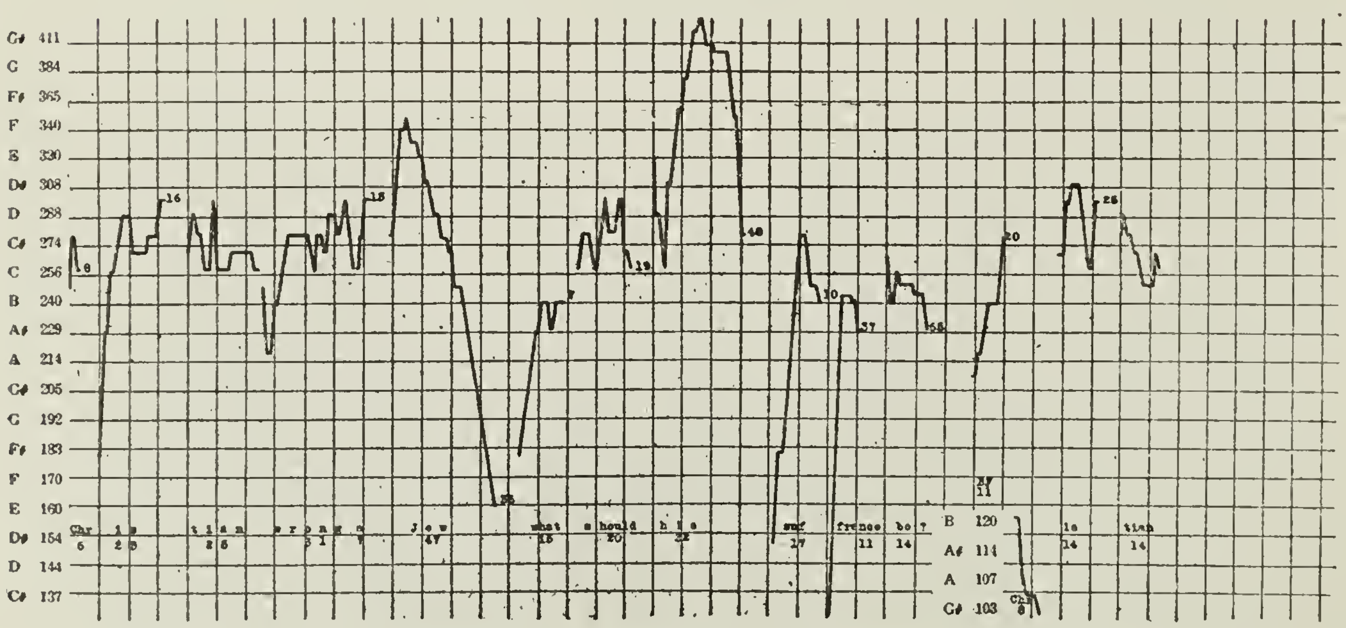
revenge? If we are like you in the rest, we will resemble you in that.

FIG. 15.



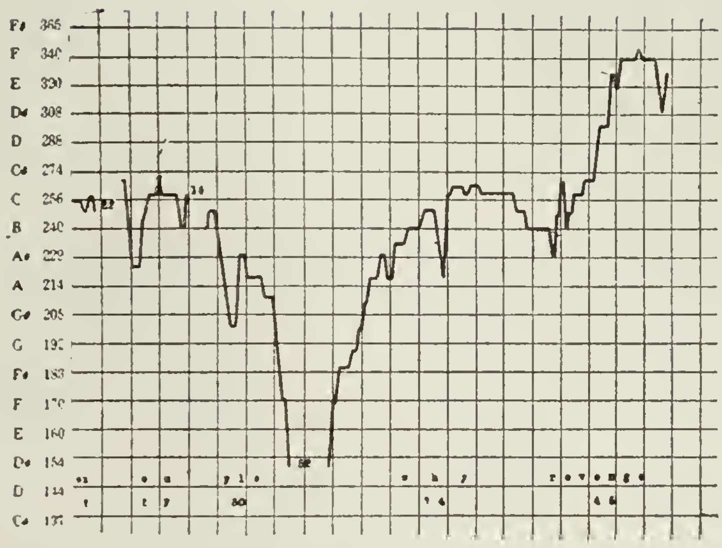
If a Jew wrong a Christian, what is his humility? Revenge! If a

FIG. 16.



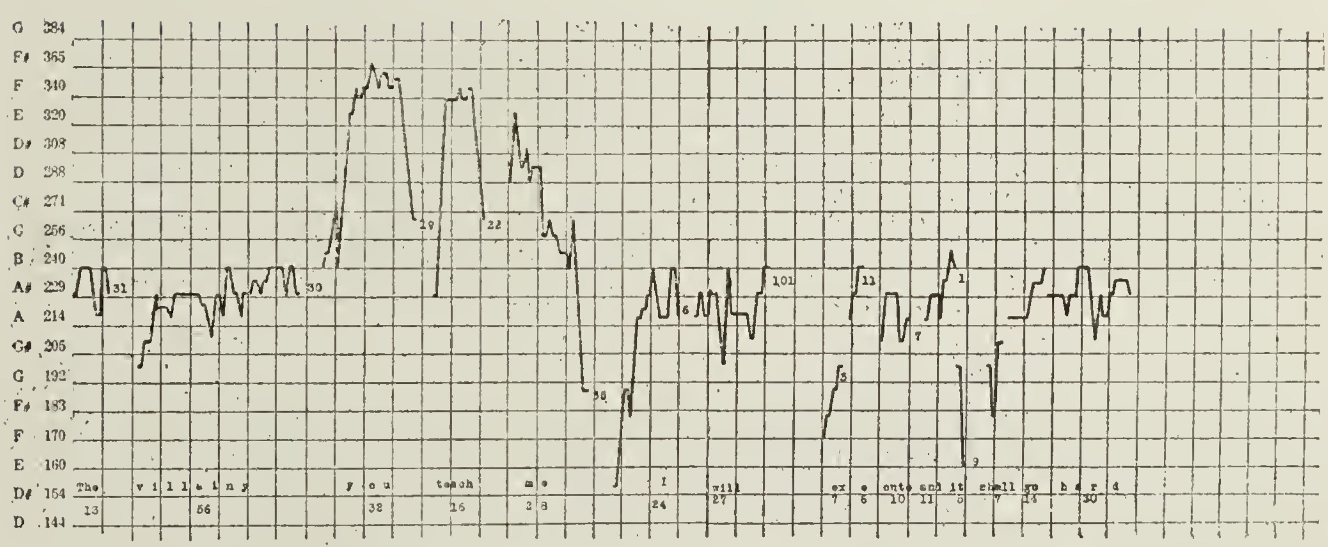
Christian wrong a Jew, what should his sufferance be? By Christian

FIG. 17.



example, why revenge.

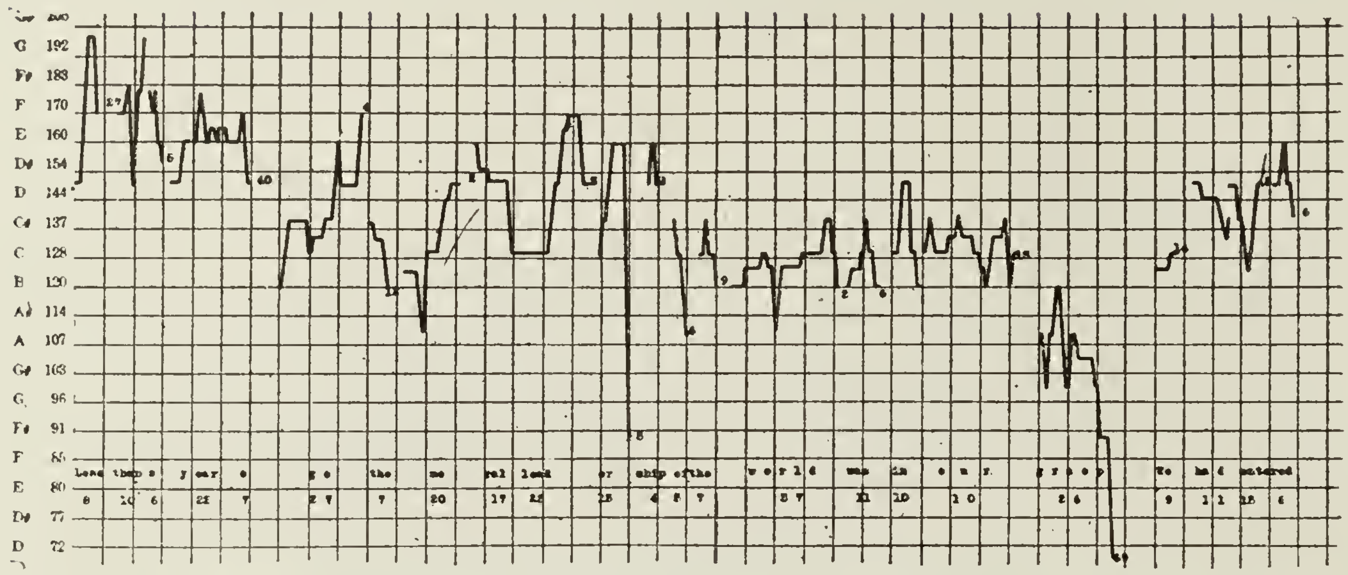
FIG. 18.



The villainy you teach me I will execute and it shall go hard. . . .

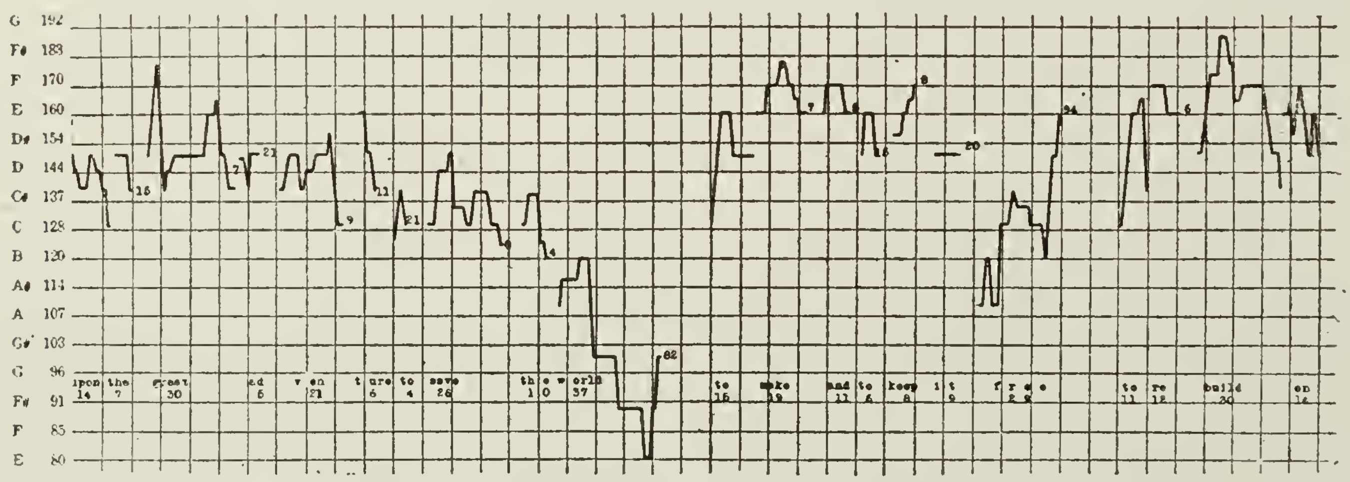
FIG. 19.

Graphs Series B, Figs. 20-31. Speaker: Rabbi Wise. Speech, "President Wilson." Columbia record No. 49738.



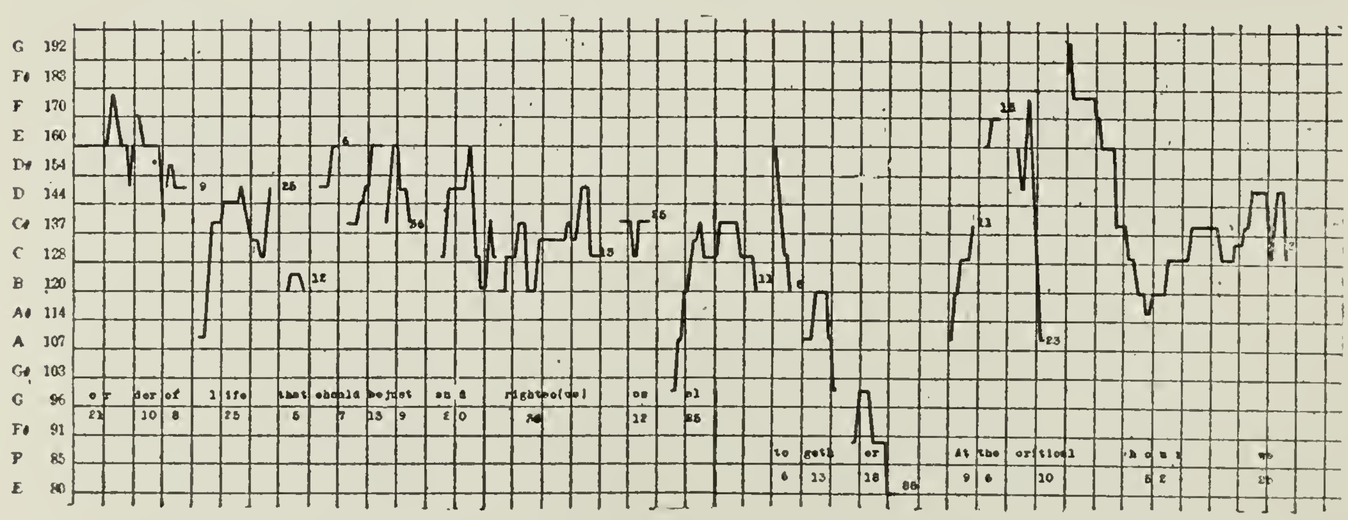
Less than a year ago the moral leadership of the world was in our grasp. We had entered

FIG. 20.



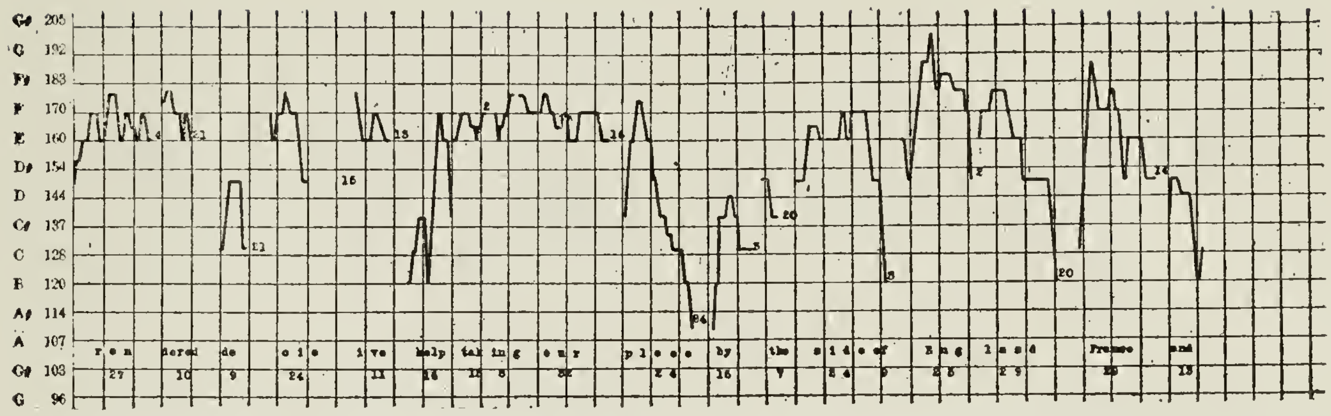
upon the great adventure to save the world to make and to keep it free to rebuild an

FIG. 21.



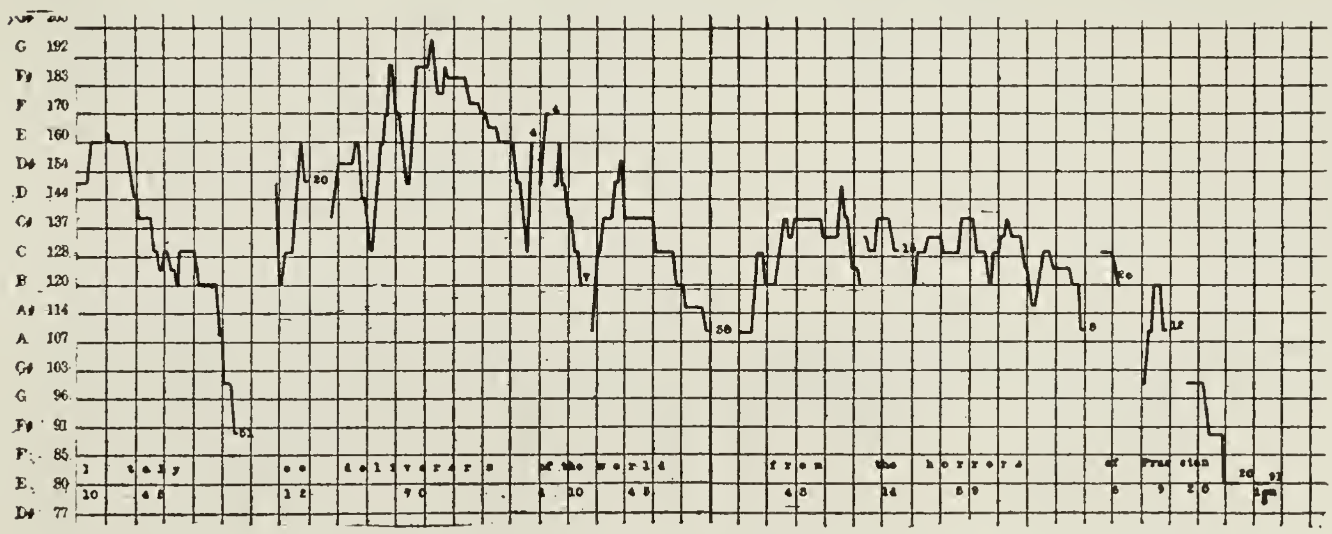
order of life that should be just and righteous altogether. At the critical hour we

FIG. 22.



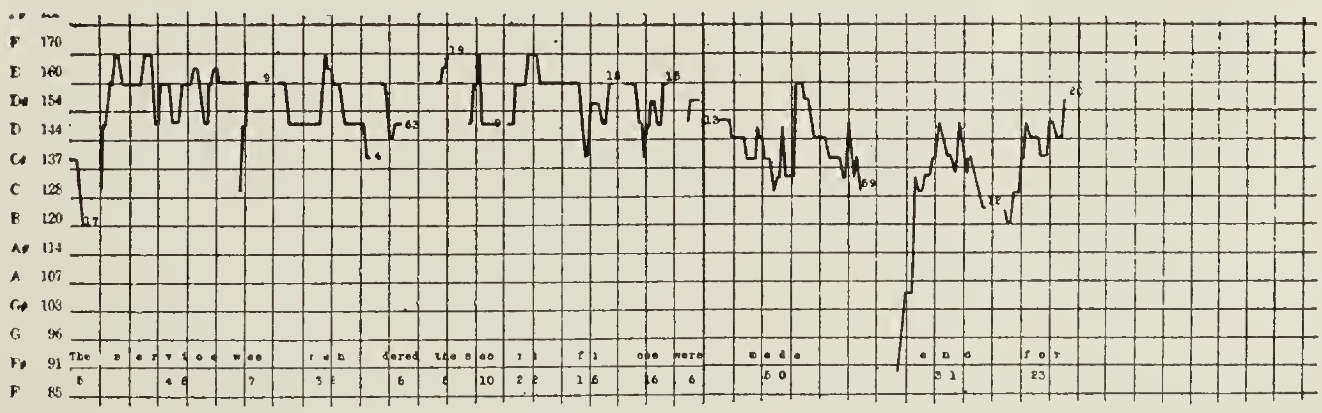
rendered decisive help taking our place by the side of England, France and

FIG. 23.



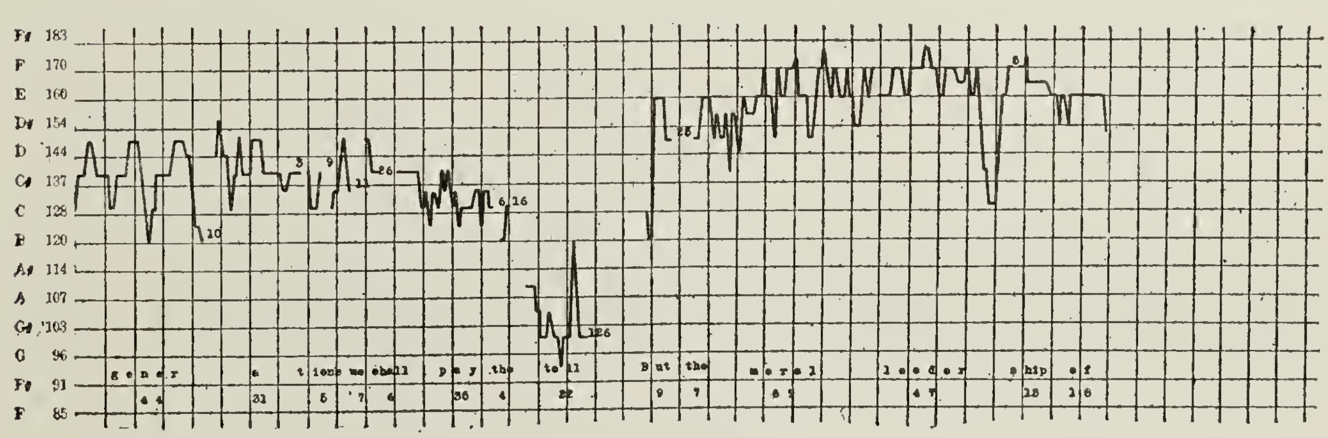
Italy as deliverers of the world from the horrors of Prussianism.

FIG. 24.



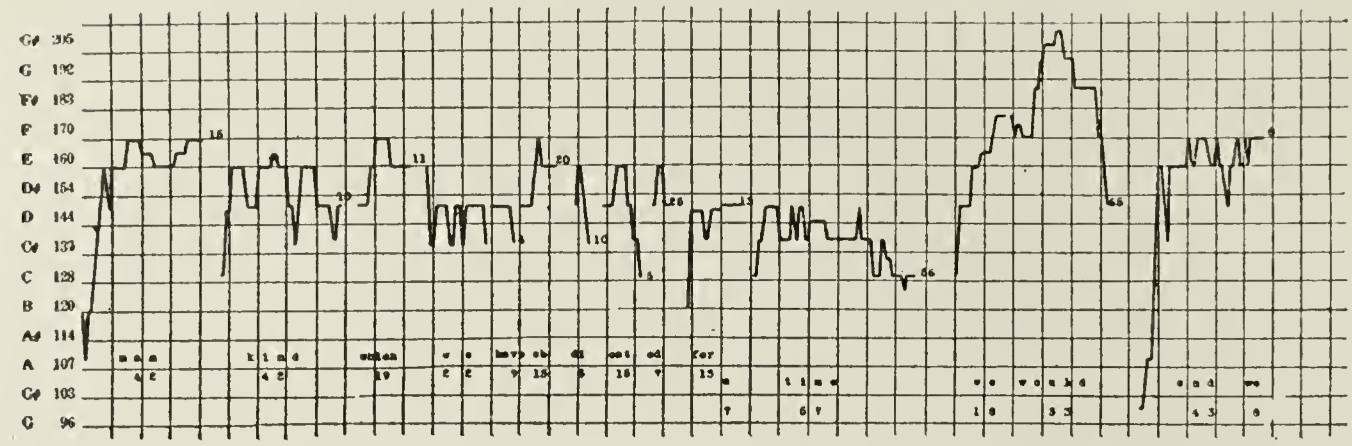
The service was rendered, the sacrifices were made and for

FIG. 25.



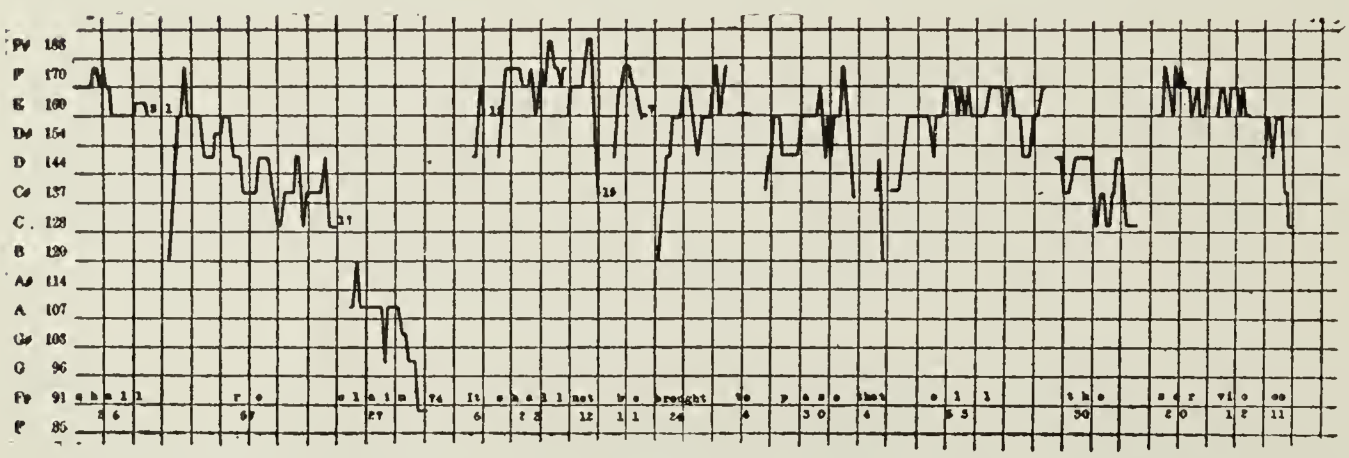
generations we shall pay the toll. But the moral leadership of

FIG. 26.



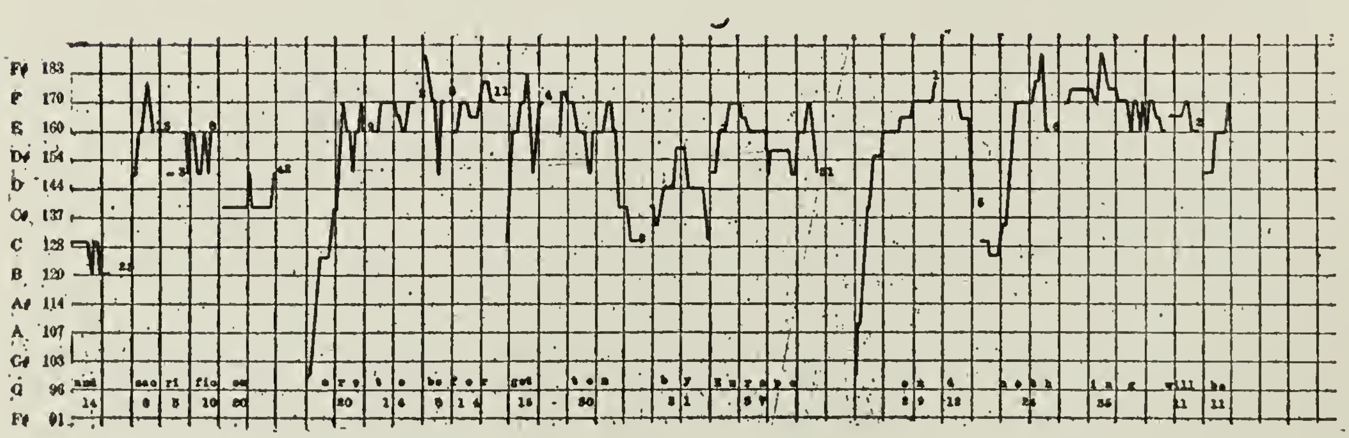
mankind which we have abdicated for a time we would and we

Fig. 27.



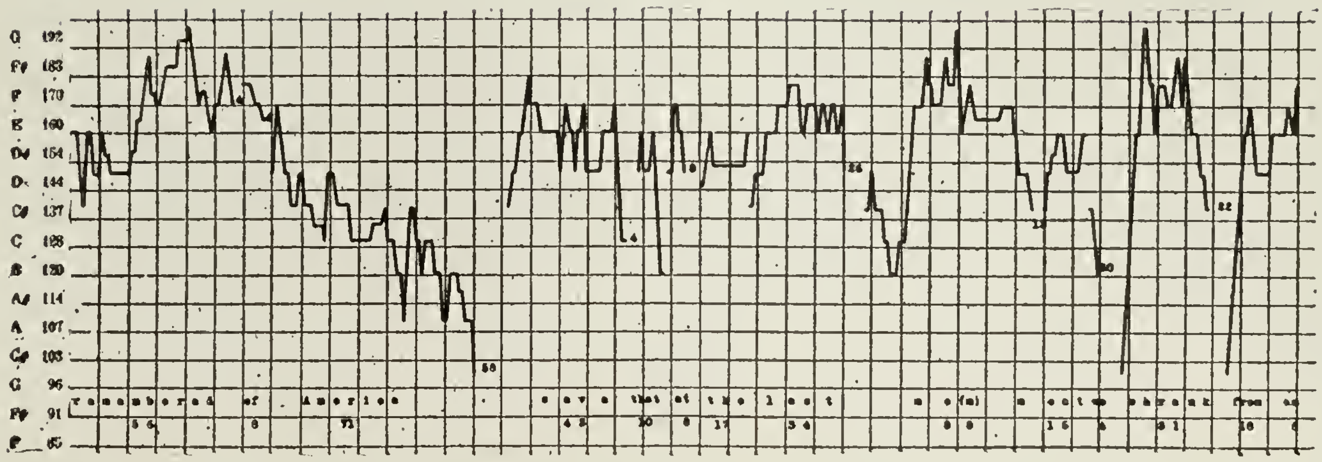
shall reclaim. It shall not be brought to pass that all the services

Fig. 28.



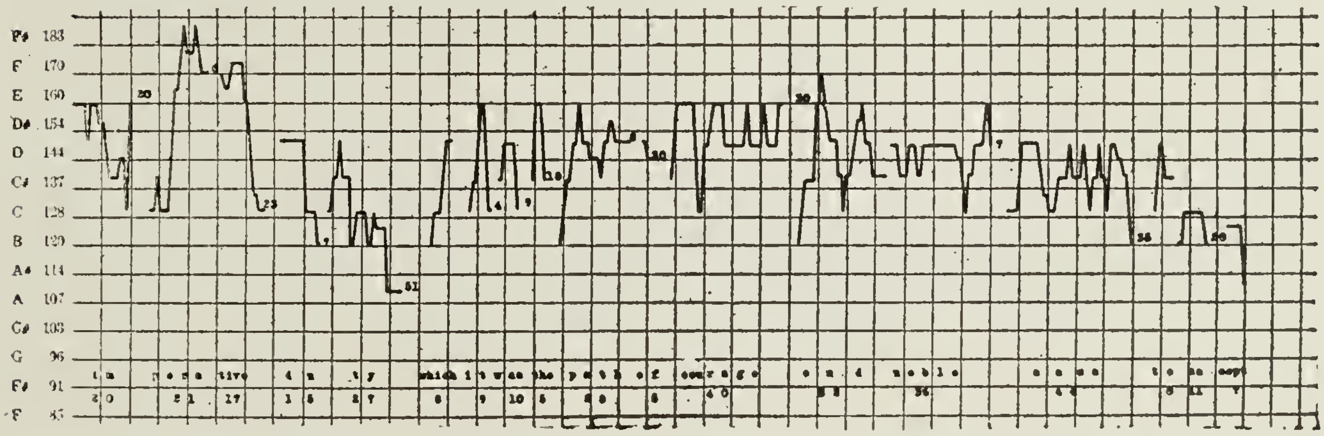
and sacrifices are to be forgotten by Europe and nothing will be

Fig. 29.



remembered of America save that at the last moment we shrank from an

FIG. 30.



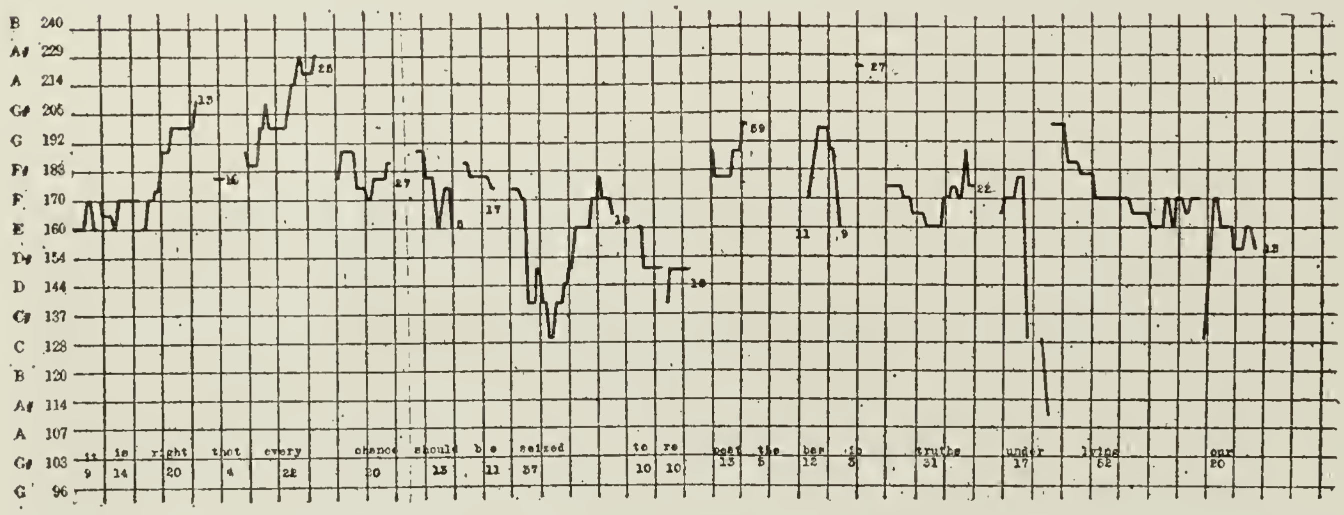
imperative duty which it was the path of courage and nobleness to accept.

FIG. 31.

Graphs Series C, Figs. 32, 33 and 34. Speaker: Franklin D. Roosevelt. Speech, "Americanism." Columbia record No. 49871.

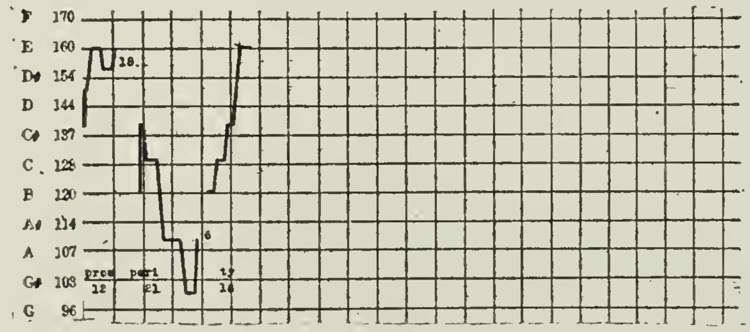
Much has been said of late about good Americanism. It is right that it should have been said and

FIG. 32.



it is right that every chance should be seized to repeat the basic truths underlying our

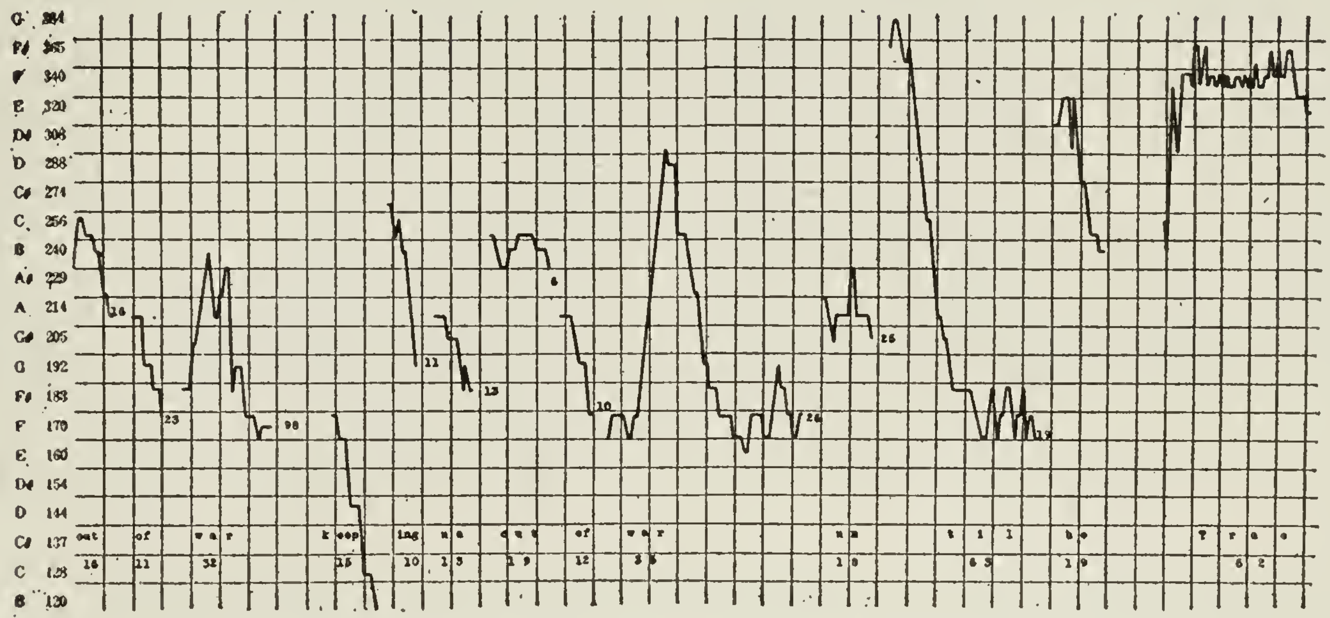
FIG. 33.



prosperity.

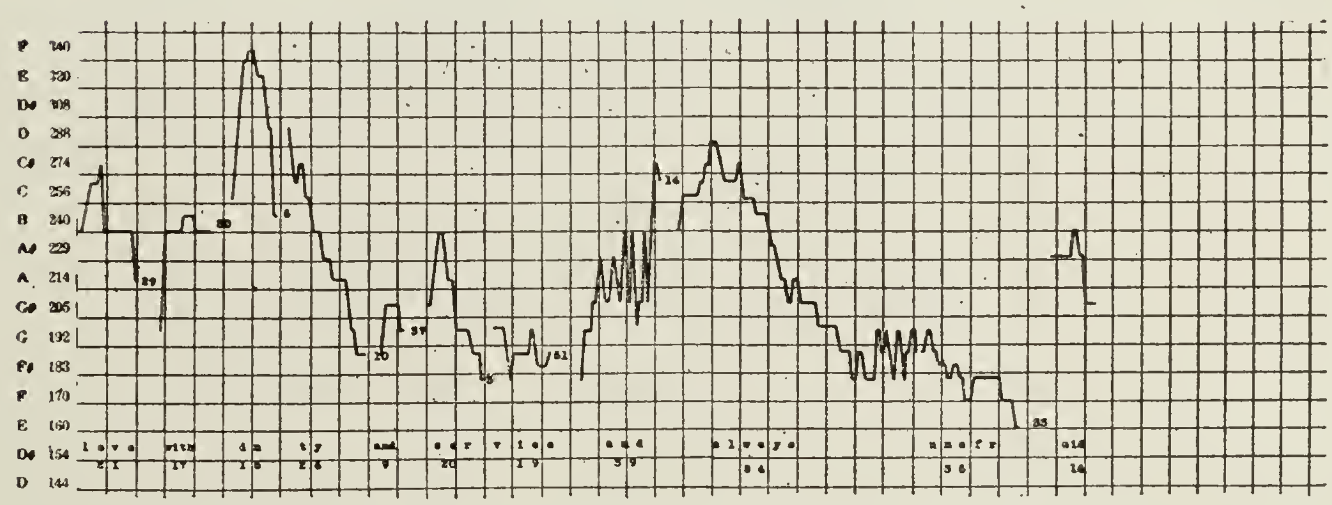
FIG. 34.

Graphs Series D, Figs. 35-38. Speaker: Mrs. Corrine Roosevelt-Robinson. Speech, "Safeguard America." Columbia record No. 49864.



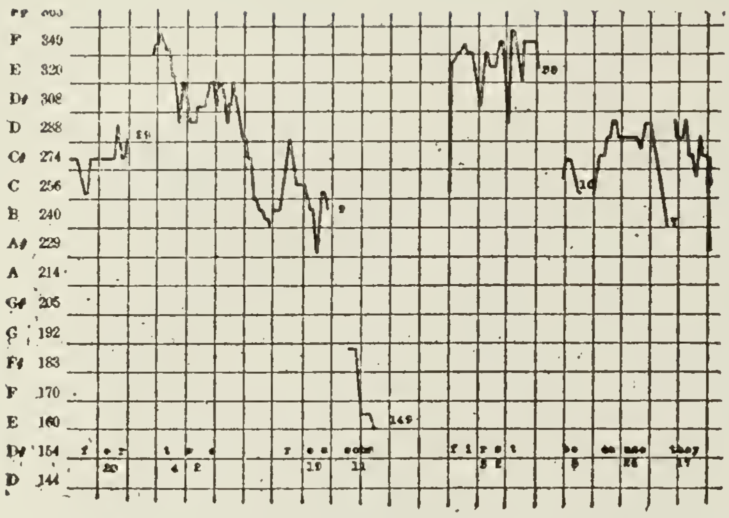
out of war keeping us out of war until he . . . . True

FIG. 35.



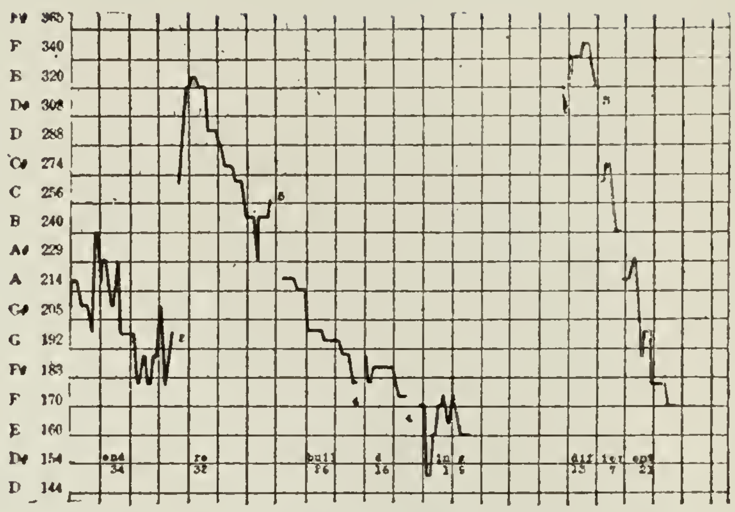
love with duty and service and always unafraid

FIG. 36.



for two reasons; first, because they

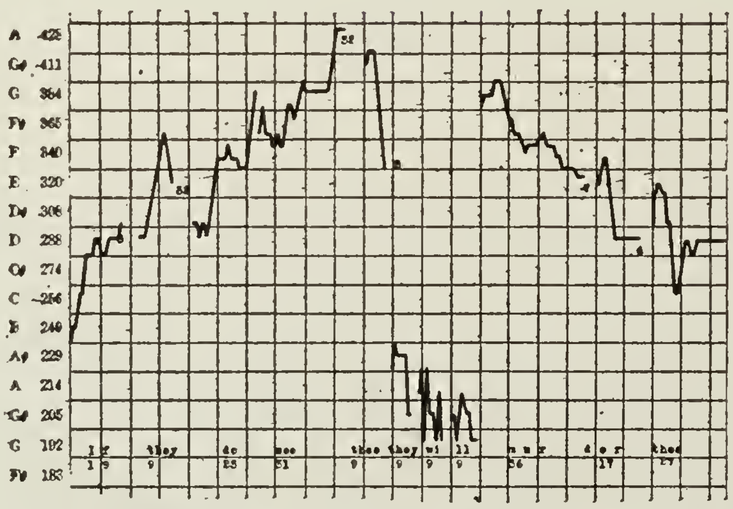
FIG. 37.



and rebuilding different

FIG. 38.

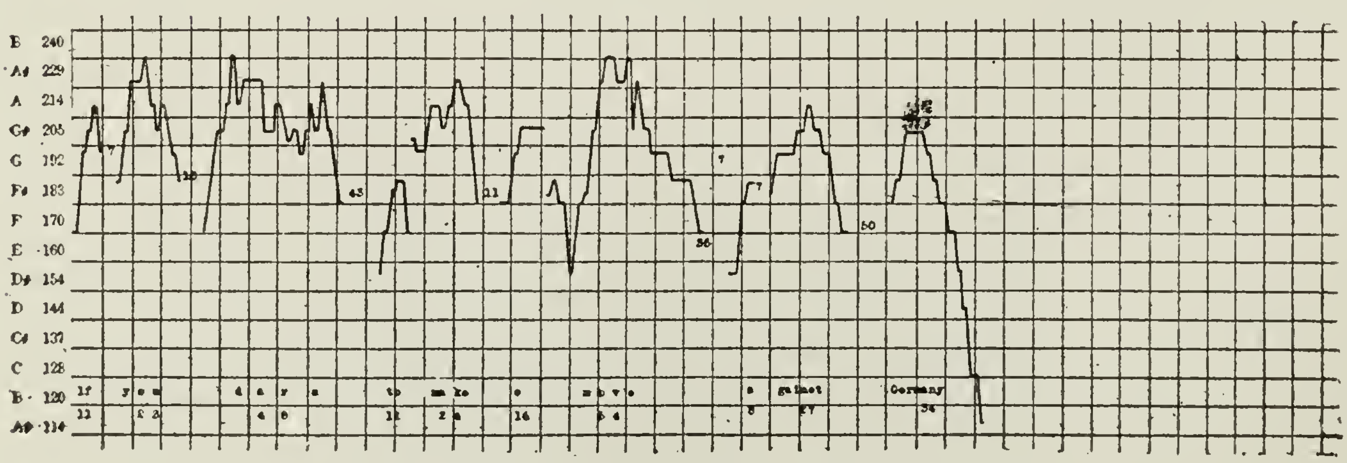
Graphs Series E, Fig. 39. Speaker: Julia Marlowe. Portia's Speech. Victor record No. 74673.



If they do see thee they will murder thee.

FIG. 39.

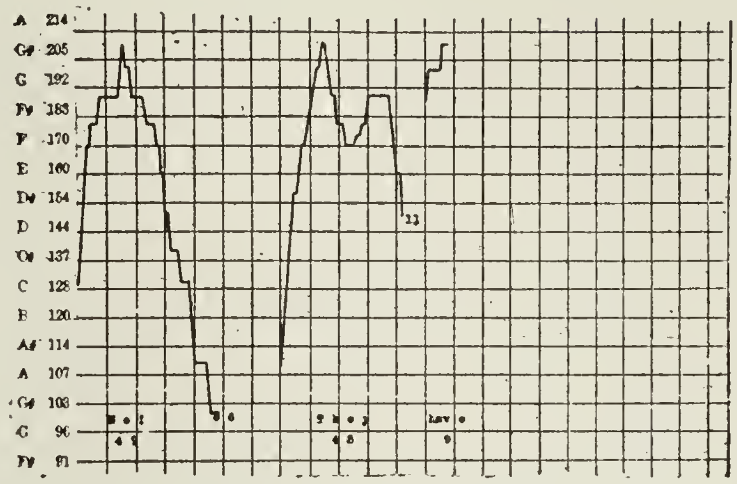
Graphs Series F, Fig. 40. Speaker: James W. Gerard. Speech, "Loyalty," Columbia record No. 77666.



If you dare to make a move against Germany

FIG. 40.

Graphs Series G, Fig. 41. Speaker: William G. McAdoo. Speech, "Revise Taxes." Columbia record No. 49706.



No! They have

FIG. 41.

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1. SCRIPTURE, E. W. *Stud. Yale Psychol. Lab.*, VII, pp. 10-14.

2. SEASHORE, C. E. *Measures of Musical Talent—Sense of Pitch, Columbia Graphophone Company, New York.*

3. SEASHORE, C. E. The Tonoscope. *Univ. of Iowa Stud. in Psychol.*, IV, 1914, pp. 1-12.

AN EXPERIMENTAL STUDY OF THE PITCH FACTOR IN ARTISTIC SINGING

By

Max Schoen, Ph.D.

I. Intonation: individual characteristics; general conclusions on intonation.
II. The Vibrato: the nature of the vibrato (intensity, pitch, period); the significance of the vibrato; the measurement of the vibrato in famous singers—Melba, Gluck, Eames, Alda, Destinn; general conclusions on the measurements of vibrato; the physiology of the vibrato.

"Songs are never sung—or intended to be sung—exactly as written. Even the most mechanical popular tune is rendered differently by each individual, the difference lying mainly in the duration of the elements, in the stress assigned to them, and above all in the attack by the voice and the utterance of each sound. In artistic performance all these sources of variation are employed, mainly unconsciously, to express the thought or emotion of the singer. Concerning just how they are varied and how they are employed there are at present no experimental data." (23, p. 488)

It was for the purpose of obtaining scientific data of these unconscious modifications of a musical melody by a great artist that the study here reported was undertaken.

Artistic singing, as all musical production, is not one talent, but a hierarchy of talents. Most of the factors functioning in effective vocal production, those of most significance, are inborn; those that may be acquired serve the better to develop and to make use of that which has been inherited. The following inventory of the singing organism follows in the main the classification given by Seashore (25, pp. 7-8) in his inventory of musical talent in general, but is here enumerated in the order of significance for singing:

1. General neuro-muscular setting
2. Acquired muscular control of the singing mechanisms
3. Musical sensitivity: pitch, intensity, timbre, time, rhythm, volume, extensity, consonance
4. Musical action: control of pitch, intensity, time, rhythm, timbre, volume
5. Imagery: auditory, motor, creative imagination

6. Tonal memory: memory span, learning power
7. Musical feeling, musical taste, emotional reaction to music, emotional self-expression in music
8. Musical intellect: musical free association, musical power of reflection
9. General intelligence
10. Personality.

A detailed account of the meaning and measurement of items 3-10 is given by Seashore (25). This study offers experimental data on the nature and significance of the first two items and may to that extent be considered a supplement to the Seashore tests.

In the main study of pitch the Seashore tonoscope (27, pp. 1-12) was used with the phonograph as accessory in various ways.[1] For the present purpose a phonograph record of the singer's voice was substituted for the actual voice. This was accomplished by connecting the turntable of the phonograph with the shaft of the tonoscope by means of belt and pulleys, the turntable thus moving synchronously with the drum of the tonoscope. The sensitive flame attachment was built into the reproducer of the phonograph so that every vibration in the reproducer registered on the tonoscope just the same as would the actual voice. The turntable could be set for any desired rate of

[1] The tonoscope works on the principle of moving pictures, technically known as stroboscopic vision. The machine converts sound vibrations into pictures on a screen. This screen has eighteen thousand and ninety-five holes so placed that, when acted upon by a sensitive flame, they arrange themselves in characteristic figures for every possible pitch within the range of the human voice. Each figure points to a number on the screen which indicates the pitch. The holes are arranged into one hundred and ten rows, the first one having one hundred and ten holes, the third, one hundred and eleven holes, and so on, each successive alternate row having one more hole than the preceding one, up to the last, which has two hundred and nineteen holes. When a tone is sounded the row which has the hole frequency that corresponds to the vibration frequency of the tone will stand still, while all other rows move and tend to blur. The row that stands still, or nearly still, therefore points to a number on the scale which designates the pitch of the tone. The tonoscope thus produces for the eye a picture of the vibrations of a tone, a picture which reveals details of pitch faithfully and far more finely than the ear can hear, thus affording a most sensitive, objective measurement of pitch. Every pitch movement of the voice is pictured on the screen, and the observer can tell at the very moment a tone is produced what error is involved, even down to a small fraction of a vibration.

revolution. Thus slow and long exposure of each tone of the composition studied made possible intensive observation. The instrumental arrangement here used is the same as that described by Merry (17).

The Bach-Gounod *"Ave Maria"* was chosen as a composition adapted for study on account of the prevalence of long sustained tones and the numerous phonograph records of it available as sung by famous artists. The renditions of the following singers, all sopranos, were selected: Nellie Melba, Alma Gluck, Frances Alda, Emma Eames, Emmy Destinn.

For the purpose of supplementing and verifying the findings with the tonoscope, the graphic method as described by Merry (17) was used. This apparatus furnishes a pantograph transcript of the phonograph record in which the amplitude of the waves is magnified about two hundred times. It was built in this laboratory during the present year, and consists essentially of a light lever tracing the waves of a phonograph record on a kymograph drum, the phonograph turntable and the kymograph drum being synchronized. An electric spark through the tracing point marks time intervals of one one-hundredth of a second. Details of time, tonal movement and number of pitch changes in a tone were secured by this means.

Under the general term "pitch" the following specific items were studied for each tone of the composition: attack, intonation, pitch fluctuations, release, tonal movement.

To facilitate the description of the mode of procedure, a single tone from the composition will be chosen and an account given of how data for the items under "pitch" were secured. Take the tone d″, the third voice tone from the beginning of the composition. It is preceded by c″ and followed by a″. Tone c″ was first registered and the movement from this tone to d″ observed. The movement might be a glide or a leap, or, in musical terms, a portamento or a legato movement. In this, the attack of the tone d″ was observed with reference to its time, pitch level and pitch inflection. The next point observed was what happened while the tone was sustained. The tone may be (1) constant in pitch, (2) fluctuating irregularly in pitch, or, (3) fluctuating periodically in pitch. The last point to be observed was the pitch on which the tone ended.

Several weeks were devoted to testing the reliability of the apparatus and to practice in accurate reading of the tonoscope and records. For the former purpose the living voice was utilized in order to make absolutely certain that none of the irregularities observed in a tone from the disk were due to some imperfection in the apparatus. The accuracy of the speed of the turntable was repeatedly tested by registering tones from instruments producing a constant pitch, such as tuning forks and orchestra bells.

The key tone for each singer was obtained from the piano reading on the tonoscope and checked up by information obtained from the record laboratory.

The Ave Maria contains 106 sung tones, ranging in duration from a whole tone to a sixteenth tone, mostly whole, three-quarter, half, and quarter notes, in the key of G major, and has a range from d′ to b″ in pitch. Data were obtained for every tone in the composition for the following nine items:

1. Attack: how a tone is attacked when preceded by (a) a higher tone, (b) a lower tone, (c) a rest, (d) when the sung tone is of long duration, and (e) when it is of short duration.

2. Release: how a tone is released when succeeded by (a) a higher tone, (b) a lower tone, (c) a rest, (d) when the sung tone is of long duration, and (e) when it is of short duration.

3. Predominant pitch: if the tone undergoes several pitch changes while sustained, on which one of the several pitches is it mostly held, and what is the number and extent of the deviations above and below this predominant pitch?

4. Vowel: the effect of the vowel on which the tone is sung on the pitch of the tone.

5. Tonal movement: how the singer moves from tone to tone, whether by glides or leaps, and to what degree. Thus, in the case of a glide, the movement may be heavy and slow, the voice dwelling upon every vibration intervening between the two tones, or it may be light and quick so as hardly to be perceptible to even the most acute ear.

6. The crescendo: the effect upon the pitch of a rise in the intensity of the tone.

7. Successive predominant pitches: when the same tone is sung several times in the course of the composition, how do the predominant pitches of the tone in the successive repetitions compare with one another?

8. Deviations: how the deviations above and below the predominant pitch of the sung tone compares with the standard pitch for that tone in pure and tempered intonation. For the tones sung in this selection, a difference between pure and tempered intonation exists only in the perfect fourth (2 dv.) and the major sixth (1 dv.); these differences being so slight that a tendency on the part of the singer to sing either sharp or flat

FIG. 1. The tone *a′* as sung three different times by five different singers showing:

A, Attack
B-F, How the tone is sustained
G, The release
I, Pitch of standard tone as obtained from the piano
J, The average attack
K, Pitch of predominant sung tone (average pitch)
L, Release above and below
M, Average deviation above and below
N, Maximum deviation above and below
O, Rise of pitch in crescendo
P, Initial of singer

NORM TONE (at the bottom)

A, Standard pitch
B, Attack
C, Pitch of sung tone
D, Release
E, Average deviation above and below
F, Maximum deviation above and below
G, Rise of pitch in crescendo
I-M, Effect of vowel on pitch.

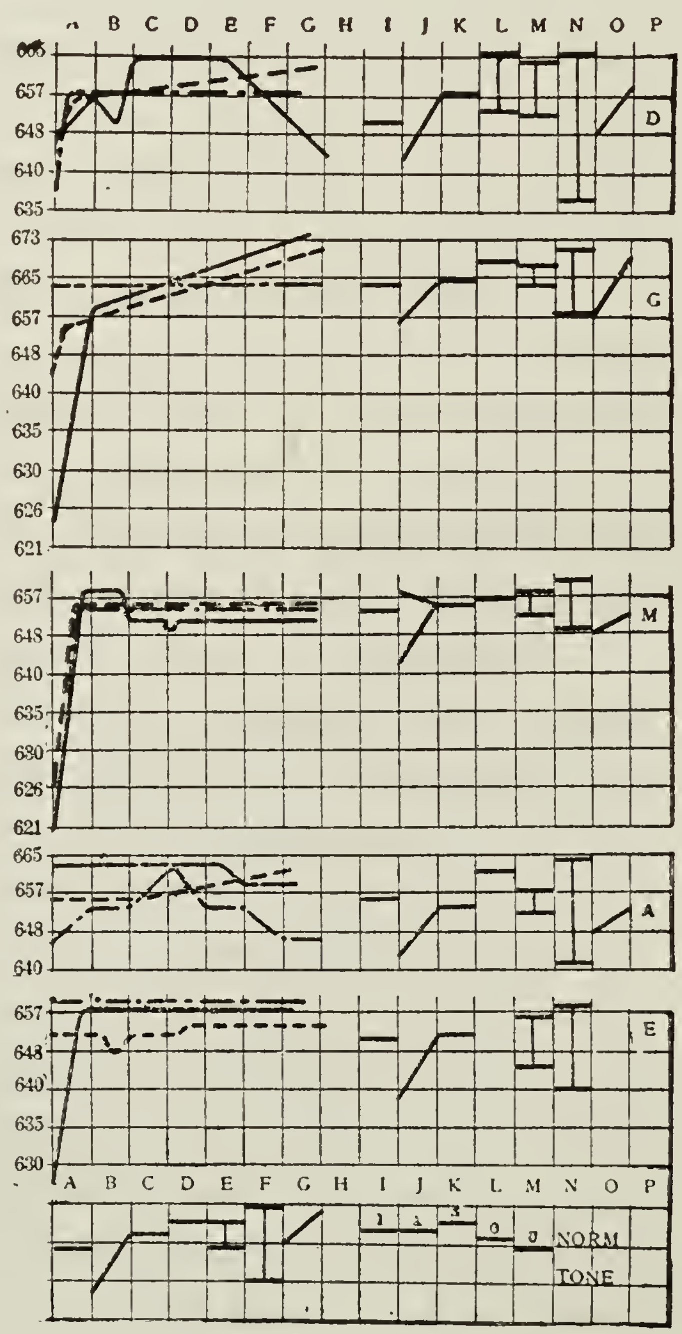

FIG. 1. INTONATION

will appply in respect to both the pure and tempered scale. The tempered scale is therefore made here the basis in the graphs and the discussion of the results.

FIG. 1 shows graphically the results of the measurements on Intonation for the five singers. Each singer is represented by two graphs, one graph showing individual tone, (the same tone as it is sung three different times throughout the composition), and the other graph showing a type indicative of the general characteristics of the singer. Finally, at the bottom, a graph showing a norm tone for all the singers is given. In each case the graph shows the nine items defined above.

A description of the items represented in the figure for one tone for the first singer (D) may aid the reader to better interpret the graphic representation of the results.

The numbers at the left indicate pitch in terms of vibrations (dv.). Thus, the number 648 means a tone of that number of vibrations per second, or tone e″, 4th space of the treble clef. This tone, however, may be of vibration frequencies differing from each other within several vibrations, the exact number of vibrations depending upon the pitch in which the instrument is tuned. Thus, in the *Ave Maria,* the pitch of e″ varies slightly in vibrations for the five singers, although the composition is sung in each case in the key of *G.* Thus, for Melba g′ is 393 dv., Destinn, 390 dv.; Gluck, 398 dv.; Alda, 394 dv.; Eames, 390 dv. This difference in the key tone of the piano is indicated in the graph for e″ by the heavy horizontal line in column I, being 655 dv. for Melba, 656 dv. for Alda, 664 dv. for Gluck, 650 dv. for Eames, and 650 dv. for Destinn. Further, since a tone produced by the human voice is not steady but rises and falls slightly in pitch, it was necessary to indicate the frequency, form and extent of this variation. These are represented by the irregularly curving line as scaled by the numbers at the left, the interval from one number to the other, or from one square to the other, vertically, measuring 1/10 of a tone.

The duration of the tone is represented horizontally, each square indicating .5 sec.

We are now ready to follow the course of a single tone on the graph. We shall take the tone represented by the solid line in Singer D.

The true pitch of that tone as obtained from the piano is 650 dv., and is indicated in column I. If this tone were sustained by D throughout on the same pitch, and sung exactly in true pitch, it would appear on the graph as a straight line on the level with the line in I. But we see that it begins at about 648 dv., then rises in the first .5 sec. of its duration to about 656 dv., or almost 1/10 of a tone, by the next .5 sec. it drops to 651 dv., and rises again to 655 dv., approximately 1/5 of a tone from the beginning of the attack; there it stays for a little over 1.2 seconds, and then it gradually drops to 644 dv., where it ends, thus having described a fluctuation within a range of 1/4 of a tone.

The same tone sung in two other parts of the selection is registered in the same manner in the other two lines.

The average extent of the glide in the attack for every time this tone occurs in the selection is shown by the height of the slanting line in (J). Thus, as compared with the standard pitch in column I, Singer D attacks the tone about 1/10 of a tone low, ends the attack about 1/15 of a tone sharp (column K), and releases her tones from 3/100 to 3/20 of a tone high (column L). The average extent of the fluctuations that take place in her tones above and below the predominant pitch as well as the standard pitch is 3/25 of a tone (column M); the largest pitch changes that occur run from 1/7 of a tone above to 1/6 of a tone below the standard pitch (column N); and finally we see that she has a marked tendency to raise the pitch when a crescendo takes place (column O).

At the bottom of Fig. 1 a norm tone is recorded. This was obtained from the averages of all the tones in the composition for each of the singers for the items shown.

This is to show that, in terms of the standard pitch, (column A), the singers initiate a tone on the average 1/10 of a tone low when the sung tone is preceded either by a rest or a tone of lower pitch (column B). The attack when the preceding tone is above the sung tone is clean (column B). In terms of the standard pitch, the singers sing sharp about 1/25 of a tone (column C).

The tone is released sharp, about 1/30 of a tone in terms of the predominant pitch, and about 1/15 of a tone in terms of the standard pitch (column D). The extent of the average deviations above and below the predominant pitch is about the same, 1/30 of a tone, (column E), while the extent of the maximum deviations above and below the predominant pitch is 3/40 and 1/12 of a tone respectively (column F).

The record of the effect of the vowel on the pitch of the tone, shown in columns I-M, is based upon the data obtained from the averages of the predominant pitches of three tones, namely, c″, d″, e″, for the following number of cases: *i*, 28 times; *a*, 26 times; *e*, 18 times; *o*, 12 times; *u*, 6 times.

Individual Characteristics

Emmy Destinn.—1. The low attack predominates, and is of large extent. Irrespective of the position of the preceding tone, the sung tone is never attacked high.

2. The release is predominantly above and of comparatively large extent.

3. A predominant tone is slightly present, the fluctuations being large in extent and numerous, with the deviations above the predominant tone outnumbering those below.

4. The effect of the vowel on the pitch is erratic.

5. A pitch rise in the crescendo is almost always present.

6. The tonal movement is a marked portamento.

7. The deviations from each other of the predominant pitches for the same tone are marked and numerous. Thus, the tone d″, sung twelve times, occurs on five different pitches within the range of 545-573 d.v.

8. A tendency to sing sharp, in terms of the predominant tone, is manifest.

9. In both pure and tempered intonation D. sings markedly sharp.

Alma Gluck.—1. When the tone is sung after a rest or after an inspiration or is approached from an interval more than a major second below, it is invariably initiated on a pitch somewhat below the desired tone, the extent of the error in attack depending on the distance, below, of the preceding tone. The low attack is most marked in extent when the tone is preceded by a rest, and is also more marked in a tone of long duration than in one of shorter duration. When the preceding tone is above, the attack is invariably clean.

2. The release is predominantly high, irrespective of the succeeding tone, and is of marked extent.

3. The aperiodic fluctuations in the tone are few, of small extent, and more numerous above than below the predominant pitch. A predominant pitch is present to a marked degree, and is continuous rather than intermittent.

4. There is a tendency for the vowels i, a, e, to be sung higher than o and u.

5. The movement from tone to tone is mostly in the form of glides (portamento).

6. In the crescendo tone there is invariably a rise in pitch of marked extent.

7. The deviations from each other of the predominant pitches for the same tone, as sung in successive occurrence, are very small in extent and few in number.

8. The maximum deviation below the predominant pitch is greater than the maximum deviation above, but the general tendency is to sing sharp in terms of the predominant tone.

9. In both pure and tempered intonation G. sings sharp.

Nellie Melba.—1. The low attack is almost constantly present and of large extent.

2. The release is unusually clean.

3. A predominant tone is conspicuously present, the fluctuations are very few and of small extent, with the departures above and below the predominant tone about evenly divided in number.

4. Vowel e is sung higher than the other vowels, i and a next, and o and u lowest.

5. The tonal movement is very smooth and legato.

6. There is rarely a rise in pitch on the crescendo and when it occurs it is of small extent.

7. The deviations from each other of the predominant pitches for the same tone are small in number and extent.

8. The tendency to sing above or below the predominant pitch is very slight.

9. In both pure and tempered intonation M. sings sharp.

Frances Alda.—1. The low attack predominates, but is of comparatively small extent. The attack from above is clean irrespective of the position of the preceding tone.

2. The high release is almost constantly present, and is of large extent.

3. The presence of a predominant tone level is not marked, and is intermittent, while the fluctuations are numerous and of large extent, being about evenly divided in number above and below the predominant pitch.

4. The vowel tendency is erratic.

5. The portamento tonal movement is markedly present.

6. A pitch rise in the crescendo is not very frequent but of large extent when present.

7. The deviations from each other of the predominant pitches for the same tone are very numerous and of large extent. Thus, out of twelve repetitions the tone d″ is sung on nine different pitches within a range of from 565-589 dv., and the tone e″, out of eleven repetitions, is sung on seven different pitches within the range 639-659 dv.

8. The maximum deviation below is larger than that above the predom-

inant tone, but the general tendency is to sing sharp in terms of the predominant tone.

9. In both pure and tempered intonation A. sings flat.

Emma Eames.—1. The attack as a whole is clean, excepting after a rest in which case it is initiated markedly low. A high attack occurs once and is of very small extent.

2. The release is usually clean, but when a deviation does occur, the tone rises slightly.

3. The presence of a predominant tone is unusually marked and continuous, the fluctuations being few, but of large extent when they occur, the deviations above outnumbering those below.

4. No constant vowel tendency is present.

5. Tonal movement is in the form of a slight portamento.

6. No tendency for the tone to rise in the crescendo is noticed.

7. The deviations from each other of the predominant pitches for the same tone are of large extent but few in number.

8. The tendency to sing off pitch in terms of predominant pitch is very marked.

9. In both pure and tempered intonation E. sings sharp.

General conclusions on intonation

1. A tone is almost invariably attacked below the pitch intended when it is preceded by a lower tone, and in the majority of cases it is released above. The size in the error of attack depends on the distance below of the preceding tone—the greater the distance, the greater the error. The largest error occurs when the tone is sung after a rest. The size of the error also depends on the duration of the tone, the longer the duration the larger the error. When the preceding tone is above the tone sung, the attack is clean. The high release is independent of the succeeding tone.

The cause for the low attack may lie in the fact that a time interval elapses before the intensity of breath pressure requisite for the production of a tone of a certain pitch is fully established. In other words, the singer does not immediately, on striking a tone, set up a tension in the cords adequate for the production of the desired pitch. Though this swooping up to a tone is no doubt at times intentional, particularly under great emotional stress, it is evident from its universality that the phenomenon is to a certain extent beyond the singer's control.

The high release may be due to an attempt on the part of the singer to maintain a steady pitch to the very end of the tone, with the result that with the waning of breath the final effort is somewhat over-reached.

2. A tone is very rarely sustained on the same pitch for an interval of time beyond half a second, the number and extent of the deviations depending on the individual characteristics of the singer.

3. Two tones of the same pitch and of equal duration are never sung twice the same way; they vary in the number and the extent of the fluctuations as well as in the pitch of the predominant tones.

4. The vowel quality seems to have but an insignificant effect on the pitch of the tone, although there is a slight tendency to sing the vowel *e* highest, *a* and *i* next, and *o* and *u* lowest.

5. The five singers are divisible into three classes in the matter of tonal steadiness and the number and extent of the fluctuations: Melba and Gluck having the steadiest voices with the fewest and smallest fluctuations, Eames having a steady tone with few fluctuations, but of marked extent when they occur, while Alda and Destinn manifest unsteady tones with fluctuations large in number and extent.

6. The movement from tone to tone is predominantly in the form of glides, but varying in degree for the different singers, being heavier for some than for others.

7. A tendency for a rise in pitch with a rise in intensity is manifest throughout.

8. There exists a tendency for all the singers to sing sharp in the sense that the deviations above the predominant tone are more numerous than those below, but the maximum deviations below the predominant tone are always larger than those above.

9. The singers sing in neither pure nor tempered intonation, but slightly sharp in respect to both.

PART II. THE VIBRATO

No experimental data either on the nature or the significance of the vibrato in singing are available—a strange fact in view of the prominence of this phenomenon in every voice manifesting a singing quality. Even the little speculative literature in existence on the subject is, to say the least, confusing and contradictory.

Recently Mr. Thomas Edison was accredited with an interview (6) to the effect that out of approxmiately 3800 records of singers examined by his force there were but 22 who sang what he calls pure tones, "without extraneous sounds and the almost universal tremolo effect. . . . Most singers can not sustain a note without breaking it up into a series of chatterings or tremolos. The number of waves varies from two per second to as high as twelve. When at the latter rate, the chatter can just be heard and is not very objectionable. If this defect could be eliminated, nothing would exceed the beauty of the human voice, but, until this is done, there will be only a few singers in a century who can emit pure notes in all registers."

Some representative expressions of opinion on this vocal manifestation from singers and voice teachers may be given:

"This vibration in the voice should not be confused with a tremolo which is, of course, very undesirable. A voice without vibrato would be cold and dead, expressionless. There must be this pulsing quality in the tone, which carries waves of feeling on it." (3, p. 145)

"It is scarcely necessary to describe the tremolo. Five out of every six modern singers are afflicted with it, and consequently there is a great deal of make-believe that the tremolo is a splendid vehicle for the expression of sentiment and passion. . . . It may be pointed out that all great singers preserve their voices much longer than the average artists, and while the latter usually show the tremolo, the former invariably never do." (19, p. 25)

"There is a desirable vibration or pulse which should be in every tone and which gives it life. This the old Italians called the vibrato; it is quite different from the tremolo. The vibrato is the natural pulse or rhythmic vibration of the tone, and in the attempt to keep the voice steady this must not be lost; any control which prevents this natural vibrato or life-pulse from entering the tone is as bad, though not so obvious, as the tremolo itself." (31, p. 85)

'The vibrato is a rhythmic pulsation of the voice. It often appears in untrained voices; in others it appears during the process of cultivation. Some have thought it the perfection of sympathetic quality; others deem it a fault. —The vibrato is caused by an undulating variation of pitch or power, often both. The voice does not hold steadily or strictly to the pitch, and according to the amount of the variation a corresponding vibrato, or tremolo, is produced.—The action of stringed instruments illustrates this statement. The finger of the violinist vibrates on the string by rocking rapidly back and forth and the vibrato is the result.—The same holds true of the human instrument. By variation of the tension, the vocal apparatus sends forth several tones in alternation, of a slightly different pitch, which together produce the effect.—Three sources are ascribed for the vibrato; one is a rapid, spasmodic vibration of the diaphragm causing variation of breath pressure; another is the alternate tension and relaxation of the larynx and vocal cords; a third is that commonest of faults—throat stiffness. Either cause is possible, and variation in the pitch or intensity of the tone is the result. Sufficient investigations have not been made to make the matter certain, but tremolo, trembling of the vocal organs, and muscular stiffness, or unnatural tension seem to go together.—It is quite possible in the early stages of culture so to train the voice as to use the vibrato or not at all at will, but if not early controlled this, like other bad habits, gains the mastery. Excessive vibrato has spoiled many good voices. It is not a fundamental quality of the voice. A little vibrato may occasionally be desirable when properly and skillfully used; more than this is to be shunned as a dangerous vice." (7, pp. 80-81)

"Thus, certain passions, and perhaps all passion when pushed to an extreme, produce (probably through their influence over the action of the heart) an effect the reverse of which has been described: they cause a physical prostration, one symptom of which is a general relaxation of the muscles, and a consequent trembling. We have the trembling of anger, of fear, of hope, of joy; and the vocal muscles being implicated with the rest, the voice too becomes tremulous. Now, in singing, this tremulousness of voice is effectively used by some vocalists in pathetic passages; sometimes indeed, because of its effectiveness, too much used by them." (29, p. 412)

What is vibrato? What is its significance in the singing voice? What is its general physiological cause? Where is its physiological seat? And what is the secret of its psychological effect? It was for the purpose of obtaining experimental data on these questions that the folowing study was undertaken.

The nature of the vibrato

The determination of the nature of this vocal manifestation involved a preliminary investigation along two specific lines: first, what type of auditory stimulus would produce an experience similar to that of the vibrato synthetically; and, second, the behavior of the tonoscope under tonal manifestations similar to that of the vibrato. If the vibrato could be reproduced synthetically and the mode of its appearance on the tonoscope compared with that of the actual voice vibrato, the comparison would serve as a clue to the nature of the phenomenon under consideration.

The vibrato may be produced instrumentally by (1) a tone that oscillates periodically in intensity, (2) a tone that oscillates periodically in pitch within certain pitch limits, and (3) a combination of both. An intensity oscillation is produced by sounding two tuning forks of 5 dv. difference into a resonator, thus producing the phenomenon of beats, or by sounding a single tone into a resonator and passing the hand in front of its mouth at the rate of five or six times a second. By using the same two forks and sounding them alternately into a resonator at the rate of five or six times a second the pitch analogous to the vibrato will be produced. An experiment conducted by the writer on a class containing twelve musicians of long experience indicated clearly that within certain limits the human ear can not distinguish easily between a pitch and an intensity oscillation, especially when the fluctuations take place rapidly and periodically.

In so far, then, as its effect on the ear is concerned, the vibrato may be either a pitch fluctuation, an intensity fluctuation, or a combination of both. When registered on the tonoscope the pulsating tone discloses to the eye a periodic up and down movement of several adjacent rows of dots, the movement being synchronous with the audible pulsations. Since all previous studies on the tonoscope concerned themselves with a tone of constant, or relatively constant, pitch and intensity, it became necessary for the present purpose to make a comprehensive study of the stroboscopic effect of a tone of varying aspects in pitch and intensity. Thus, a tone may be (1) constant in both pitch and intensity, (2) constant for one of these and fluctuate in the other, (3) constant in intensity and fluctuate periodically in both pitch and intensity.

Since the vibrato is essentially a tone of marked periodic pulsations we shall concern ourselves only with the appearance on the tonoscope under the types of periodic pulsations mentioned.

A. *Intensity.*—(1) Two tuning forks, 99 dv. and 100 dv. respectively, were electrically energized and made to speak into a resonator connected by a rubber tube with the manometric flame. The result is that when the two tuning forks are brought to the mouth of the resonator powerful beats, at the rate of one per second, are heard. The manometric flame rises and sinks in brightness synchronously with the beats while an area on the tonoscope that embraces a section above and below the two generating tones is alternately and gradually illumined and darkened, the period of illumination lasting longer than that of non-illumination. No oscillatory movement is present, but a periodic appearance and disappearance of the drum surface. The pitch of the tone is the center of the two generating tones.

(2) A tuning fork of 100 dv. electrically energized and speaking into a resonator connected by a rubber tube with the manometric flame. The purpose here is to produce a tone from a single source, of constant pitch, but the intensity of which may be interrupted periodically. This is accomplished by passing the hand in front of the mouth of the resonator at any rate desired by the experimenter, thus gradually interrupting the tone at equal intervals. The manifestation on the tonoscope is in every detail similar to that described in 1 above except that the pitch of the tone registers 100 dv.

B. *Pitch.*—Two tuning forks of 98 and 103 dv. respectively, electrically energized and connected with a telephone receiver made into a manometric flame. A shuttling arrangement makes it possible to sound each tone alternately in the telephone receiving while shutting out the other, thus producing a pitch fluctuating tone. As tone 98 dv. is sounded, the row of dots corresponding in number to this pitch stands rigidly still while the rows to its left are moving downwards, and those to its right upwards. When tone 103 dv. is presented, row 103 stands still while the rows to the left are moving down and those to the right are moving up. Now, since the rows between the two tones are exposed when either tone is registered, and, since they move in different directions for each of the tones, it is evident that when the two tones are alternately registered these rows will move up and down, the speed of the oscillation depending on the rate with which the tones are interchanged. We have here an effect on the tonoscope where two rows of dots are seen to stand still alternately, while the rows between them oscillate periodically up and down.

It now remained to make a careful study of the contour of the voice vibrato on the tonoscope and to ascertain which one of the forms described above it resembled. For this purpose the turn-table of the phonograph was slowed down to 6 revolutions per minute, which produced undulations at the rate of approximately one per second, while a capsule attached to the diaphragm of the reproducer and connected with the ears of the experimenter by means of a listening tube made every tone sung plainly audible even at this slow speed. When this slow pulsation was registered on the tonoscope a single glance at its contour made it evident that the vibrato was a pitch undulation of the type described in B. One difference, however, was clearly evident between the vibrato of the voice and that of the tuning forks; namely, that, whereas in the latter the rows of dots between the two pitch limits appeared and disappeared suddenly as the tone was switched from one pitch to the other, in the former there was a gradual piling up of the rows of dots in the waving form, indicating that in the voice vibrato the movement from pitch to pitch is in the form of a gradual glide while in the synthetic vibrato, as is evident, the movement is a clear jump from one range of the fluctuation to the other.

We conclude, then, that one of the factors in the vibrato is a periodic glide, up and down, of the sung tone, within certain pitch limits, the glide being synchronous with the pulsations as heard by the ear.

For the purpose of determining the range of the pitch changes in the vibrato the following procedures were followed, the one procedure serving as a check upon the others: (1) All rows within the range of the vibrato oscillate up and down, the extent of the oscillation of each row depending upon its proximity to the row that stands still. To illustrate, supposing that the tone fluctuates between rows 128-138, then row 133, the central row between the two limits would undergo the largest oscillation while row 127 would oscillate least when the tone is on 128 and row 137 when the tone is on 138. Consequently, in order to determine the range of a periodically fluctuating tone it is only necessary for the experimenter to observe one end of the fluctuation at a time and carefully watch for the last row that has an undulatory motion. The pitch is one row below this last oscillating line when the lower limit is observed and one row above the last oscillating line when the upper limit is watched. (2) As stated previously, when a tone of constant pitch is registered on the drum, the rows to the left of the tone move downwards and those to the right move upwards. Therefore, to obtain the lower limit of the periodic pitch-changing tone the experimenter observes the first row that moves downwards; the pitch is then one row above. For the upper limit he observes the first row that moves upwards, and then the pitch is one row below.

An assistant was seated close to the experimenter to write down the readings as these were called out. One end of the fluctuating tone was studied at a time and its pitch determined by each of the methods described. The readings from the different methods were then compared, and if they did not tally, the study of the same tone was resumed. Marked facility in catching accurately the readings in a few observations is attained after practice.

The rate of the vibrato was determined by counting the number of undulations in the tone at the slow speed and then ascertaining carefully the actual duration of the tone at the normal speed of the phonograph, 78 revolutions per minute.

To ascertain whether intensity functioned in any manner in the vibrato, recourse was had to a vibrating mirror (15, pp. 415-460).

The first experiments with the Rayleigh disk were conducted on the living voice. The observers were students of voice and singers from the University School of Music. The singer was instructed to cup her hand around the rubber tube leading to the diaphragm and to sing a tone on any vowel into the tube. In all cases, whenever a pulsation was present in the tone the spot of light would oscillate periodically and synchronously with the pulsation. When no pulsation was heard in the tone the spot of light would become elongated and remain relatively rigid throughout the duration of the tone.

A detailed study of the intensity factor in the vibrato was next undertaken for the five singers. The tube leading from the disk diaphragm was connected with the capsule of the phonograph reproducer while a millimeter screen was placed one metre from the disk. Repeated attempts to get an intensity response from the recorded voice showed that the disk would respond only to a certain range of pitches for a given speed. It therefore became necessary to change the speed of the phonograph for different tests of pitch. This proved to be no disadvantage, however, since the main purpose was to make comparison of the extent of the intensity fluctuations for the same tone for each of the five singers. It was thus possible to measure the intensity of most of the tones in the composition in terms of amplitude of oscillation in the image on the screen. To obtain a response from the highest tones the turn table revolved at a speed of about 11 revolutions per minute, giving very slow oscillations on the screen. This made it possible to observe the form of the intensity pulsation in the same manner as pitch was observed in the tonoscope. The same tone could then be compared wave by wave for both pitch and intensity and the relation between the two deduced.

Conclusions.—The graphs in Figure 2 show the range of the vibrato for pitch and intensity for characteristic individual tones for the highest, middle, and lowest ranges of the composition, namely b‴, d″, and f′. To the right of the individual tone a norm for the pitch extent of the vibrato for that range is shown. The pitch extent is given in terms of vibrations and part of a whole tone, each square representing 1/10 of a tone, and the intensity in terms of millimeters, each square being equal to 10 mm. The absolute intensity of the tone is indicated and also the extent to which there is an intensity fluctuation. The time element is represented horizontally, each square measuring 1/6 of a second. The vibrato pulsations are represented as equal (1/6 sec.) because this rate is so nearly uniform that variation in successive waves in different notes and for different singers did not seem to be significant.

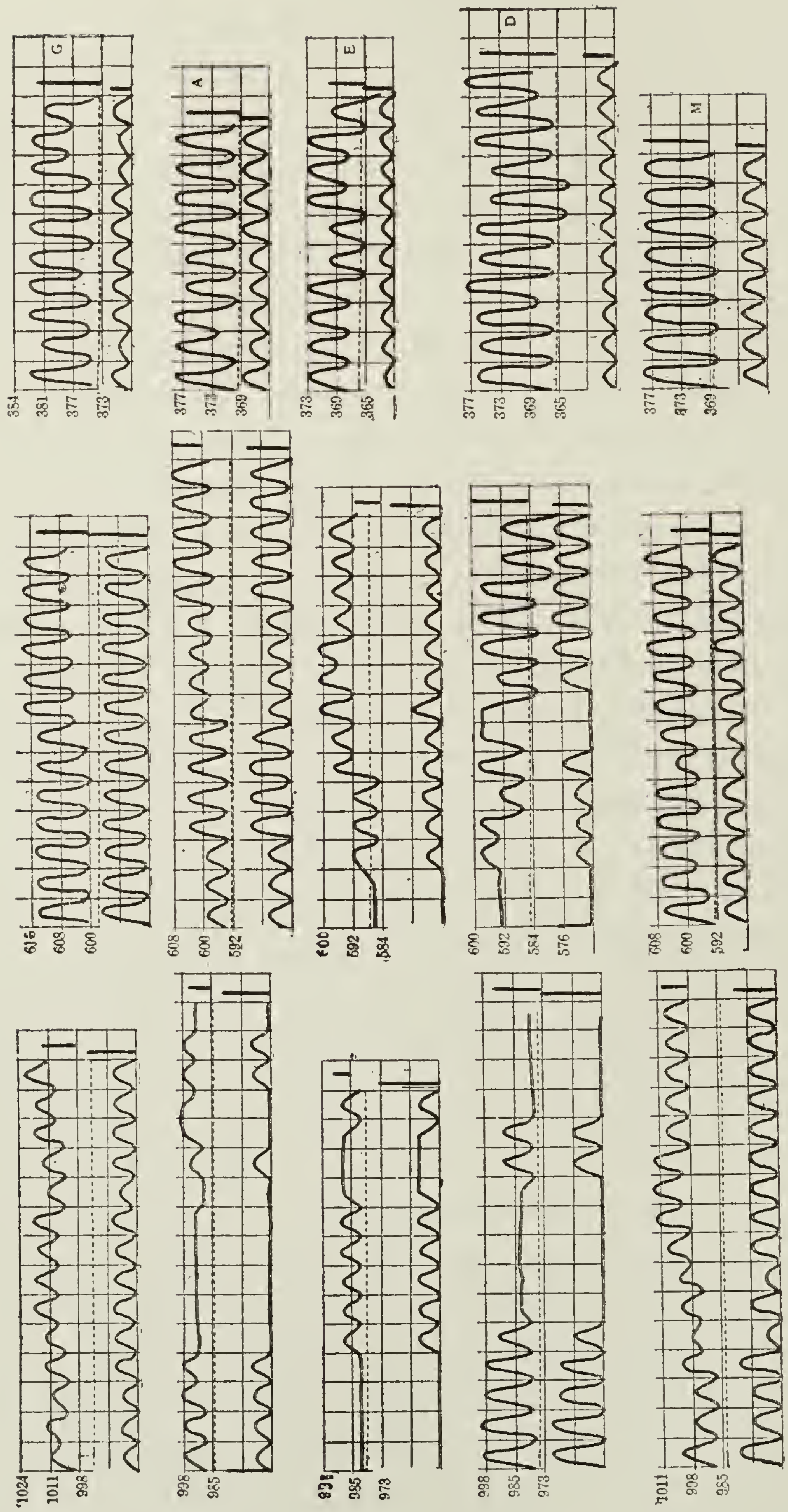

FIG. 2. *The vibrato.* Each singer is represented by three tones (from left to right), the first from the high range of the selection (b′′′), the second from the middle range (d′′), the third from the low range (f-sharp′).

The capital letter at the right identifies the singer.

For each tone the upper curve indicates the extent, form and pitch of the pitch changes in the vibrato in terms of 1/10 of a tone. The heavy vertical line to the right of each upper curve represents the average extent of the vibrato as obtained for the three highest tones for each range, namely, g′′′ a′′′ b′′′ for the highest range; b′ c′′ d′′ for the middle range; e′ f-sharp′ g′ for the low range.

The lower curve shows the synchronous intensity deflections of the tone measured in terms of galvanometer deflections at a distance of one meter. The heavy vertical line to the right of the curve indicates the absolute intensity of that tone.

The dotted line shows the true pitch of the tone in tempered intonation as obtained from the key tone of the piano.

The numbers at the left designate the pitch in terms of vibrations, each block representing 1/10 of a tone.

For intensity each block represents 10 mm.

The horizontal time unit is 1/6 of a second.

An interpretation of the graphic representation in Fig. 2 of the pitch and intensity undulations for one tone follows:

The tone is the third one, counting from the left to right, for Singer G.

The tone begins at 375 dv., and during the first 1/6 of a second rises to about 382 dv., and drops back to 375 dv., having described a wave 1/5 of a tone in extent. During the next 1/6 of a second the tone describes a wave from 375 dv. to 381 dv. and back to 375 dv., while during the third 1/6 of a second the first wave is repeated. In the fourth time interval the tone rises from 375 dv. to 376 dv., with an undulation to 382 dv., while in the next period the tone drops back to 375 dv. and the first wave recurs twice. During the eighth interval the tone rises to 368 dv., and we see the vibrato diminishing in extent until the tone ends on 374 dv.

As compared with the standard pitch shown by the dotted line we see that the tone is sung slightly sharp, if the lower limit of the fluctuations is considered the pitch of the tone.

The average extent of the vibrato at the low range of the voice is slightly over 1/5 of a tone, as indicated by the heavy vertical line to the right.

In the lower curve we see the intensity oscillations of the same tone, with the maximum intensity of that tone represented by the heavy vertical line to the right. In the case of this tone we note that not only are the intensity changes coördinated with the pitch changes in time and extent, but that the intensity oscillation is so marked that the tone practically dies out for each vibrato pulsation. The graph is not intended to indicate the relative prominence of the pitch and the intensity fluctuations, by showing the latter on a smaller scale. Psychologically, the intensity fluctuation is often as clearly perceptible as the pitch fluctuation in a good voice vibrato.

A study of the pitch and intensity data yields the following conclusions on the nature and general characteristics of the vibrato:

1. The vibrato is a pitch-intensity fluctuation.
2. The pitch and intensity waves are not only synchronous,

but also coördinate, a large pitch wave being accompanied by a large intensity wave, and vice versa, rise in pitch coinciding with increase in intensity.

3. The absolute intensity of the tone does not seem to have any effect on the range of the vibrato.

4. In terms of vibrations the extent of the vibrato is about the same throughout the entire range of the voice, being 10, 11, and 12 dv. for the lowest, middle, and highest ranges, respecttively, or 0.25, 0.15, 0.09 in terms of part of a whole tone.

5. There are marked individual variations for both the extent and the manner of manifestation of the vibrato.

6. The rate of the vibrato is approximately 6 oscillations per second, and is approximately constant.

The significance of the vibrato

For the purpose of determining the significance of the vibrato in vocal expression the voices of twenty persons were studied, ranging in age from fourteen years to middle age and in vocal ability from the monotone to a celebrated concert artist. These observers were divided into four classes, as follows: (1) the monotones; (2) untrained, non-musical voices, (3) untrained, musical voices, (4) trained, musical voices. A careful study of these classes of voices on the tonoscope yielded the following conclusions:

1. The monotones: To the ear the voice sounds dull, hard and strident. On the tonoscope the tone of the monotone registers almost rigid, non-fluctuating.

2. The untrained, non-musical voice: The tone sounds dull, but not as hard and strident as in the monotone. The tonoscope shows a tone from this voice to fluctuate irregularly above and below a predominant pitch within two to four vibrations.

3. The untrained, musical voice: The tone sounds bright in comparison with those of (1) and (2), and a slight pulsation is clearly heard. The pulsation has a marked periodicity of about 6 pulsations per second. Only in the case of one singer did the rate of the pulsation reach 13 per second. When observed on the tonoscope the following phenomena are seen to take place in

this type of voice: (1) a progressive fluctuation in pitch above and below a predominant pitch, and (2) a periodic rise and fall in pitch ranging in extent from six to twelve vibrations, and synchronous with the audible pulsations. Not every tone sung, however, shows the periodic fluctuations. But whenever a pulsation is present the periodic fluctuation is also invariably present.

4. The trained musical voice: For this voice the observations reported for class (3), with the addition that both the pulsations and the pitch fluctuations are more markedly present, hold.

To summarize.—(1) In the musical tone of both trained and untrained voices a periodic pulsation is heard. (2) the rate of the pulsation is about 6 per second. (3) When the pulsating tone is registered on the tonoscope it is seen to have a periodic pitch fluctuation of from six to twelve vibrations in extent. (4) This pitch fluctuation is synchronous with the audible pulsations. (5) This periodic fluctuation appears above, and in addition to, a progressive fluctuation. (6) When the singer was told to control the pulsation in the voice, that is, to try to eliminate it, she could do so only for a fraction of a second and reported that it was very difficult to sing alone under such conditions. (7) The vibrato is a fundamental attribute of an effective singing voice.

Measurement of the vibrato in famous singers

We are now in a position to interpret the significance of a conclusion arrived at in the preceding section, namely, the presence of marked individual variations not only in the extent of the vibrato but particularly in the manner of its presence in the voices of the five singers. An analysis of the individual characteristics gives the following results:

Melba.—The vibrato is constantly present, with an average amplitude of 10 vibrations. The voice has a marked uniformity and constancy of timbre and pitch throughout the entire range of the composition.

Gluck.—The vibrato is constantly present in every tone with an average extent of 13 vibrations. Its presence is most marked in the middle and low ranges and least in the highest range of the composition.

Eames.—The vibrato is intermittent, being present in some tones and absent from others, as well as present in one part of a tone and not in another part. When the latter case occurs the tone usually begins without the vibrato and ends with a vibrato. The average range is 6 vibrations. The voice as a whole, as well as single tones, lacks uniformity in timbre. The vibrato is mostly absent from the highest tones of the composition.

Alda.—The vibrato is present in every tone, but is intermittent. It has an average extent of 8 vibrations, but is quite variable in the same tone. This gives the tone an effect of constantly changing timbre.

Destinn.—The tone almost invariably begins minus the vibrato and ends with the vibrato. The effect on the ear is that of a tone beginning with one timbre and ending on another. The average extent of the vibrato is 16 vibrations.

General conclusions on the vibrato

1. The vibrato is a fundamental attribute of the artistically effective singing voice in that it is a medium for the conveyance of emotion in vocal expression.

2. The vibrato is a manifestation of the general neuro-muscular condition that characterizes the singing organism.

3. The psychological effect of the vibrato is probably due to the fact that the human ear has, because of the behavior of muscle under emotional stress, come to associate a trembling with emotional experiences.

4. The voice that possesses the most constant vibrato, constant in its presence in the tones throughout the range of the singer's voice, and of an amplitude and an intensity not obtrusive to the ear, but of sufficient intensity to be easily audible, has the best effect on the hearer, provided the other factors that enter into artistic singing are present.

5. The rate of the vibrato is relatively constant, of approximately six pulsations per second, with an average amplitude of eleven vibrations for the five singers here studied.

6. The intensity fluctuations are synchronous with the pitch

fluctuations wave by wave for both rate and extent, the average intensity amplitude for the five singers being 13 mm.

The physiology and psychology of vibrato

It is well known that the nervous discharge accompanying feeling of any kind is both diffused and restricted. The diffused discharge serves as the measure of the intensity of the emotion and its effect on the muscles is in an inverse ratio to their size and the weights of the parts to which they are attached. (30, p. 545.) It thus happens that a feeble wave of nervous excitement will manifest itself most in the muscle or muscles where it meets with least resistance. Thus in man it will act first on the delicate muscles of the voice and the small facial muscles, and then the arms, legs, and the trunk. In the restricted discharge we are dealing with the production of a special effect due, in the words of Spencer (30, p. 545), "to the relations established in the course of evolution between particular feelings and particular sets of muscles habitually brought into play for the satisfaction of them, and partly due to kindred relations between the muscular actions and the conscious motives existing at the moment." It seems, then, that while every emotion will have a general effect on the entire musculature of the organism, its effect is marked particularly upon one set of muscles, the specific set of muscles depending on the nature and the quality of the emotion.

Schäfer (21, pp. 111-117), in experimenting upon the tetanic nature of voluntary muscular contraction, has shown that during the whole extent of time that the contraction of skeletal muscle in man is maintained as a result of the excitation of any part of the nerve center, the muscle responds by undulations at an average rate of about 10 per second. Further, the rate of the rhythm is independent of the rate of excitation provided the frequency of excitation is above 10 per second. The experiments also showed clearly that although the rate of discharge is uniform and constant, the amplitude of the oscillations is irregular, being much more marked in some individuals than in others. In the words of Sherrington (22, pp. 43-44), "The rhythm of discharge from the motor cell, as far as undulations noted indicate rhythmic response, are totally different in rhythm from that of the action induced in the afferent cell by the stimulation applied. . . In such cases, therefore, the rhythm of the end-effect indicates that in transmission along the reflex arc the impulses generated at the receptive end of the arc are not actually passed on from one cell element to another in the arc, but that new impulses with a different period are generated in the course of the reflex conduction." The extreme variations obtained by Horsely and Schäfer for the rhythm of motor discharge, per second, were from 8 to 13. The same authors also state that occasionally the regularity of the undulations is interrupted by a longer and larger wave usually covering the extent of two of the smaller undulations—an occurrence which, they claim, is probably due to a more complete summation than usual of the effects of two successive nervous impulses.

Let us now inquire further into the nature of muscular discharge under particular conditions.

In 1904 Gordon Holmes (13, pp. 327-375) published an account of certain tremors in organic cerebral lesions. His observations are of peculiar interest in relation to the vibrato. Holmes defines tremor as "consisting in an involuntary oscillation of any part of the body around any plane, such oscillation being either regular or irregular in rate and in amplitude, and due to the alternate action of groups of muscles and their antagonists." In summarizing his observations on seven cases of tremor the author states that:

"The tremor consists in a series of involuntary oscillations of any part of a limb, due to the alternate contractions of one group of muscles and its antagonists, of slow rate, varying in rapidity from 3 to 5 oscillations per second, in all cases more or less regular in rate, while limited to any one group of muscles, in some cases absolutely so; generally coarse, *i.e.*, of large amplitude; with a periodical rhythmical increase and decrease of the range, or irregular.

"In no case did it persist during sleep . . . it also ceased when the limb lay at complete rest, so supported that each segment of its segments was individually supported. In each case the influence of gravity on its production and existence was emphasized; any part of the limb allowed to hang unsupported was in some cases invariably, in all cases frequently, affected by tremor. This would seem to point to a certain condition of tone of the muscle being essential to, or at least concerned in, its pathogenesis. . .

"In each case, too, it was observed that the psychical state exerted considerable influence on the intensity and character of the tremor; it always increased with any agitation or excitement of the patient, and diminished as the patient again became composed and calm."

Summarizing these facts in their bearing upon the vibrato of the singer it is evident that the vibrato is a phenomenon in every respect similar to the tremor here described. The tremor is of constant rate but varies in amplitude, so is the vibrato; the tremor is beyond the control of the patient, so is the vibrato; it only occurs when the muscle is under slight strain, so does the vibrato; it is about half the rate of normal muscular discharge, so is the vibrato.

We may then summarize the foregoing facts in their bearing upon the vibrato as follows:

Singing is essentially an emotional act, involving the neuromuscular mechanism or muscles functionally connected with this specific type of emotional expression, the whole act involving the usual type of muscular response to stimulation characteristic of skeletal muscle. Further, that the neuro-muscular apparatus of the singing organism is peculiar in kind, in that, to a certain extent it manifests those phenomena of muscle pathology found in the tremor, in that the vocal muscle, under tension, brought about as a result of the emotional excitement involved in singing, responds with a rhythm of muscular discharge at a rate half of that found in the normal state, and that this tremor is manifested particularly in that organ which is functionally connected with vocal emotional expression, the larynx.

It now remains for us to more specifically ascertain the seat of the vibrato, whether the pulsation is essentially a pitch fluctuation and therefore has its seat in the vocal cords, or whether essentially an intensity fluctuation located in the resonance mechanism. Some facts concerning the anatomy and physiology of the larynx will yield a plausible theory.

The larynx is the vibrating organ of the voice. It is situated at the base of the tongue and is so closely connected with it by attachment to the hyoid bone to which the tongue is also attached that it is capable only of slight movement independent of that organ; consequently it must move with the tongue in articulation.

Two types of movements of the larynx have been experimentally determined (16, pp. 197-212): movements of its single parts towards each other, and shifts of the larynx in toto. Here the latter movement is of interest.

The following figure from Meitner (16, p. 199) represents the possible movement directions of the normally moving larynx in deglutition, phonation, and forced respiration. N represents the static zero point, the arrow ES the direction of the forced respiratory movement, the swallowing and phonation movements for high vowels; the arrow JO the direction of the forced inspiration and phonation movements for low vowels.

| ↑ ES

N ——— | ———

JO ↓ |

What is significant for our purpose here is the fact that the larynx is not stationary in phonation, but that its position shifts with a change in pitch, or what is the same, that a change in larynx position means a change in the pitch of the sound. Taking this fact into account, plus the anatomical and physiological facts already mentioned, namely, (1) the anatomical relation between tongue and larynx, (2) the nature of the vibrato, a pitch-intensity oscillation, (3) the emotional nature of the act of singing, (4) the action of muscle under emotional stress, we may conclude that the muscle or muscles holding the larynx in suspension during the emission of a tone undulate periodically in a manner similar to the tremor, this undulation causing the small pitch changes observed in the tone, while the coördinated movements of the tongue bring about the periodic change in the resonance box and cause synchronous intensity changes.

The foregoing facts point to the following conclusions on the physiology of the vibrato: (1) The vibrato is due to a neuromuscular condition characteristic of the singing organism. (2) The vibrato is a periodic pitch-intensity phenomenon. (3) Its specific seat is in the muscle or muscles controlling the movements of the larynx in phonation.

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VOLUNTARY CONTROL OF THE INTENSITY OF SOUND

By

Dorothea Emeline Wickham

Problem.—The aim of this investigation is to establish a standard test for musical "touch." By musical "touch" is meant the more or less voluntary control of intensity of sound in music, whether the same be vocal or instrumental. Musical interpretation and expression depend to a large extent upon the difference in intensity of sound, and the degree of voluntary control of this intensity may be regarded as a measure of musical touch. Touch involves variations in pitch, timbre, volume, and time, but these are secondary to and usually derived from variations in intensity.

Self-expression through the intensity of sound rests primarily upon two factors, viz., intensity discrimination and precision in the control of voluntary movement. The solution of our problem might be approached by studying each of these separately, or by taking a measure of the capacity as a whole, and correlating with achievement. The latter is the method followed.

Again, we have a choice of setting this test for the operation of a particular instrument, such as piano or violin, or making a generic test by employing a non-musical instrument. The latter method was adopted because it lends itself to a more accurate test and is free from the effect of training in a specific instrument, the attempt being to set the conditions such that the test would measure the general capacity involved as a common factor in regulating the intensity of sound by either voice or instrument.

The test does, however, not consider the motives for expression through intensity such as feeling, imagination, or knowledge. It merely registers the capacity to control intensity.

Apparatus.—A modification of the Seashore audiometer,[1] as shown in Fig. A,[2] was used. It differs from the original mainly in that it is made to produce stronger sounds, the range being from inaudibility to a sound which is disagreeably loud to the normal ear. There are thirty-five steps in intensity determined as in the original by varying the number of turns in the secondary coil, as shown in Table I. where, after the first few steps, the increment is one-fourth and the coils are cumulative. The resulting increments of intensity of sound are approximately equally perceptible. The primary circuit is interrupted by a 100 dv. tuning fork. There are two sliding contact riders, one for the observer and one for the experimenter, mounted one on each side of the contact points so that any desired intensity within the range of the instrument may be produced by either contact operator. The sound is heard in a telephone receiver.

TABLE I. *Values for the audiometer scale*

	Number of Turns			Number of Turns	
Step	Increment	Total	Step	Increment	Total
1	1	1	19	25	123
2	1	2	20	31	154
3	1	3	21	39	193
4	1	4	22	48	241
5	1	5	23	60	301
6	1	6	24	75	376
7	2	8	25	94	470
8	2	10	26	118	588
9	3	13	27	147	735
10	3	16	28	184	919
11	4	20	29	230	1149
12	5	25	30	287	1436
13	6	31	31	359	1794
14	8	39	32	449	2244
15	10	49	33	561	2803
16	13	62	34	701	3506
17	16	78	35	877	4586
18	20	98			

Procedure.—The object to be attained with the instrument is to produce a quick glide through a series of graded intensities of sound up to a desired step, which shall then be sounded three times as a standard, and to enable the observer to perform the same act by ear guidance alone.

[1] Seashore, C. E., An audiometer. *University of Iowa Studies in Psychology*, 1899, II, 158-163.

[2] *See insert p. 207.*

The experimenter and the observer are seated on opposite sides of the audiometer, each holding a contact rider in hand, the observer being blindfolded. The experimenter starts at 0 and slides her contact along the scale evenly and approximately at the rate of one second for the entire swing, thus producing a glide from inaudible to the standard intensity. This intensity is sounded three times at the rate of about one per second, the first of these three being the sustained tone at the end of the glide. The experimenter is then required to repeat this sound by a similar manipulation of his contact.

The object of having a quick glide was to enable the observer to find the desired intensity through a gradual attack somewhat analogous to the intensity attack in instrument or voice. The standard was sounded three times by the experimenter for the purpose of giving clear and verified impression and by the observer for the purpose of giving him opportunity to correct himself in the second or third sounding if the first was not satisfactory, as the third sounding was the one recorded.

Fifteen preliminary trials were given followed by fifty recorded trials. The audiometer scale is nine inches long. Movement over any considerable part of it is therefore so large that it is quite easy to stop at the right intensity. In other words, the movement is not a smart tap, the accuracy of which depends upon a specific skill, as in piano playing, but a very simple and large hand movement of most elementary form. The ten steps, 11, 12, 15, 16, 19, 20, 25, 26, 28, and 30, were arbitrarily selected as standards representing different levels of the thirty-five degrees of intensity, and each was sounded five times, the order being determined by chance.

The principal form of error is what has been known as the time error combined with the error involved in a premature satisfaction with an approaching standard. These operating together give us a permanent constant error as shown in Table III. The time error is to the effect that, of two tones sounded in succession, the latter seems to be the louder; and the approach error, that, in approaching a standard gradually, there is a tendency to be satisfied before the standard is actually reached. Since these are normal illusions, it makes it difficult to evaluate them in the rating of achievement.

Results.—Ninety-one unselected students were given the test as described above, the record being kept in terms of steps on the audiometer. The distribution for these is shown in Fig. 2.

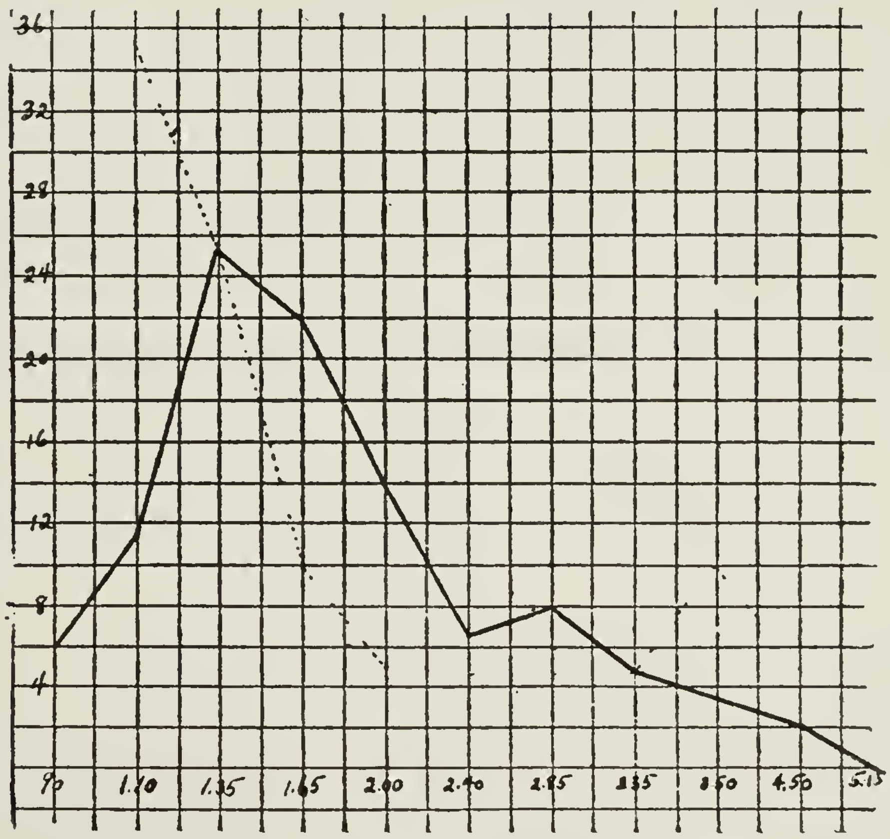

FIG. 2. Distribution of records

The average error ranged from .86 of a step to 4.72 of a step with the mode at 1.35. For convenience these were classified into five groups, as shown in Table II.

TABLE II. *Rating of cases as based on the average error*

.85	(9%)	1.15	Superior
1.16	(10%)	1.30	Excellent
1.31	(29%)	1.60	High Average
1.61	(30%)	2.25	Low Average
2.26	(18%)	3.25	Poor
3.26	(4%)		Very Poor

This preliminary norm having been established, twenty of the most advanced piano pupils in the music school, among these, were studied for the purpose of correlating their rating with achievement. The record for these is given in Table III, the cases being given with their rating as determined in the laboratory before anything was known by the experimenter about their musical achievements.

TABLE III. *Rank assigned on the basis of the test*

Average error	Constant error	Rank	Average error	Constant error	Rank
1.04	— .64	1	1.40	— .04	11
1.14	— .04	2	1.46	+ .34	12
1.18	— .30	3	1.78	+ .74	13
1.18	+ .56	4	1.78	+ .90	14
1.22	— .06	5	1.96	—1.36	15
1.22	+ .16	6	2.34	1.10	16
1.22	— .18	7	2.72	—1.60	17
1.30	— .30	8	3.12	—2.64	18
1.32	—1.09	9	3.38	—3.26	19
1.36	— .96	10	4.16	—3.42	20

TABLE IV. *Comparison of test rank and ratings*

	I	II	III
Superior	1, 2	6, 11	1, 11, 19
Excellent	3, 4, 5, 6, 7, 8	1, 5, 7, 10, 14, 19	3, 5, 6, 8, 12, 14, 16
High Average	9, 10, 11, 12	2, 3, 8, 9, 15, 18	2, 7, 9, 10, 15, 18
Low Average	13, 14, 15	4, 12, 13, 16	4, 13, 17
Poor	16, 17, 18	20	20
Very poor	19, 20	17	

I Rating from results in the test
II Rating by individual instructor
III Rating by director

Rating.—In Table IV is given the rating assigned the same pupils, first by the individual instructor in piano and second, by the director of the school of music upon the following instructions:

"We have measured the natural capacity of the student for reproducing certain standards of loudness in a tone where the loudness of the tone could be controlled with precision and measured.

"In piano playing this capacity appears most clearly in the 'touch' as evidenced in the student's ability to render accurate and graceful expression through the force of the stroke, *i.e.*, the loudness of the tone. In order to see how our theoretical finding corresponds with our observation in practice, we are asking if you will have the kindness to rate the students listed on the scale from 1—100 by putting a check mark on the dotted line in the sheet furnished to indicate the rank that you would give the student on this specific ability.

"Take into account only this one factor, excluding pitch, rhythm, time, etc. so that you judge on this one factor alone. Take training into account carefully.

"When you have rated all of the students in the list, number them in the order of certainty that you feel in your judgment."

Here we encounter a most serious difficulty in the standardizing of a test in that there is in music no definable standard of intensity, while for pitch and time there are standards and achievements that can be measured accurately. Not only is there no standard of intensity for measurement or musical guidance, but the musician seldom thinks in terms of intensity of sound as isolated, and therefore finds it exceedingly difficult to rate a person on capacity in this respect. Furthermore, piano students have had different training, both in degree and kind, and it is difficult for the instructor to differentiate between natural capacity and the result of effective training. "The appeal to teachers' judgment" in this case was made only as a last resort and with a full realization of the inadequacy of the method.

The co-efficient of correlation between the test and the rating by the director is by the Spearman formula ($R = 1 - \frac{6sd^2}{n(n^2-1}$ R, .28, P.E., .11. The correlation between the test rank and the rank by the individual piano instructors is R, .40, P.E., .11. These are low correlations and would not be regarded as satisfactory for a prognostic test if the correlation had been against a measurable quantity. It is no reflection on those who rated their pupils to say that the co-efficient of correlation between instructors' rating and directors' rating is only R, .33, P.E., .10. Table IV throws into relief the agreements and disagreements in these ratings. The instructors naturally knew the pupils better than the director who had only heard them briefly in weekly recitals.

In referring to the grouping in Table IV, we observe that the test rank agrees exactly with the director's rank in eight out of the twenty cases, is one point away in five, and two points away in five cases. There remain only two cases of extreme divergence. The test rank agrees exactly with the instructor's rank in four out of the twenty cases, is one point away in ten cases, two points away in five cases, leaving only one case of large disagreement. The director's rank agrees exactly with the instructor's rank in eleven out of the twenty cases, is one point away in six cases and two points away in three cases.

Comments on Individual Cases

Study of the individual cases in which there is marked disagreement throws much light on the reasons for disagreements in the three ranks, and shows how the correlations were cut down by the presence of circumstances not under control.

No. 2 rated superior in the test, but only high average by the instructor and the director. It was found that she had very firm piano touch but seemed to be totally unable to put expression into her playing. She undoubtedly had the ability to control the tone as she heard it, but there was apparently no inner impulse to call forth the finer distinctions in shading. In other words, her piano touch, though capable of being superior, did not reveal musical feeling.

No. 14, rated excellent by the instructor and the director, made a low rating in the test on account of her attitude. She had religious scruples against tests and approached this test in the negative attitude.

No. 11, placed in the superior group by both instructor and director, tested only high average. Analysis of the situation proved that this was due to nervousness in taking the test as she was nervously high-strung, and the test rating was therefore wrong.

No. 4, who rated excellent in the test, was a dawdler as a pupil and did not apply herself. No. 18 was just the opposite, always using her best effort to the limit of her capacity.

No. 19 represents our worst disagreement. Here the constant error raises a problem. Her average error, 3.38 is made up almost entirely of the constant error —3.26. In other words, she was very consistent, which is a form of accuracy, but was grossly misled by the motives for constant error. This raises a most difficult question as to what allowance shall be given for constant error in the rating.

Conclusion.—No far-reaching conclusions can be drawn from these preliminary experiments, but much light is thrown upon the nature of the problem as guidance for future work. The idea of using a generic test in place of a specific instrument seems to be unquestionably good, particularly in view of the fact that this test will have its greatest significance when used before a musical education has been begun.

If we may assume that the advanced piano pupils have gone through a process of selection, the skewness of the curve for these twenty pupils toward the superior end as compared with the curve for the unselected pupils may be considered evidence of such selection.

There is need of a developed technique for the rating of musical touch under laboratory conditions for purposes of this kind.

Even in those cases in which the test prognosis was not verified by the estimated achievement, valuable light was thrown upon the nature of the musical mind of the student by the test.

If objective measure of achievement in this specific capacity could be obtained, the correlation of the test with achievement would undoubtedly be very much higher than here found. The test, therefore, deserves some place in the diagnosis of musical capacity.

A COMPARISON OF THE AUDITORY IMAGES OF MUSICIANS, PSYCHOLOGISTS AND CHILDREN

by

Marie Agnew, Ph.D.

A. Musicians

The following questionnaire was sent to two hundred musicians belonging to the Music Teachers National Association:[1]

"We are seeking information about (1) the degree of tonal imagery prevailing among musicians; and (2) the judgment of musicians as to the rôle of tonal imagery in music.

"By auditory imagery (usually called mental hearing) we mean the ability to hear sounds in imagination and memory to some extent as if they were physically present to the ear.

"For the purpose of rating imagery, we use the following scale:

0—no image
1—very faint image
2—faint image
3—fairly clear image
4—clear image
5—very clear image
6—as clear as the actual hearing

"If you will have the kindness to try the two tests and answer the following questions, we shall be under obligation to you, and shall be glad to send you a published copy of the report. The names of all contributors will be kept confidential.

"Test 1. Shut your eyes and try to *hear* in your imagination the first phrase of America as played on the piano. After repeated trials, record your average grade, marking on the above scale.

"Test 2. Compose a phrase of an original melody, to be sung by a specific person, and hear it over and over again in your imagination. Record the grade of the image on the above scale.

"Questions:

1. Do you naturally recall music vividly in realistic auditory imagery?

[1] The selection was made by taking the first two hundred in the alphabetical list of members for that year. These members vary in degree of musicianship; admission to the association is elastic. It would have been interesting to see the names after the following quotations; but, after all, we are not concerned with "authority" in a field yet so unanalyzed and uncontrolled.

2. Do your compositions always come naturally to you in realistic auditory imagery?

3. Has your own auditory imagery developed or tended to regress as you have matured?

5. What significance do you attach to such differences, if any?"

The tests in the questionnaire are subject to the same sources of error which occur in the test for measuring auditory imagery. Some of the errors are exaggerated here; it is impossible to give the corrective charge; there can be no opportunity whatever for preliminary drill; the explanation cannot be full; there is danger of confusing the attribute of vividness with other attributes; there is danger also of confusing the auditory imagery with visual or kinaesthetic imagery, or of linking them inextricably together; further, there is the possibility that the observer may answer the questionnaire too rapidly to give it sufficient thought. The form of the questions would tempt one to hasty generalizations.

The curve of distribution for the 76 musicians who replied is shown in the solid line, Fig. 1. More than half of the musicians graded themselves 6 in the first test, and nearly half graded

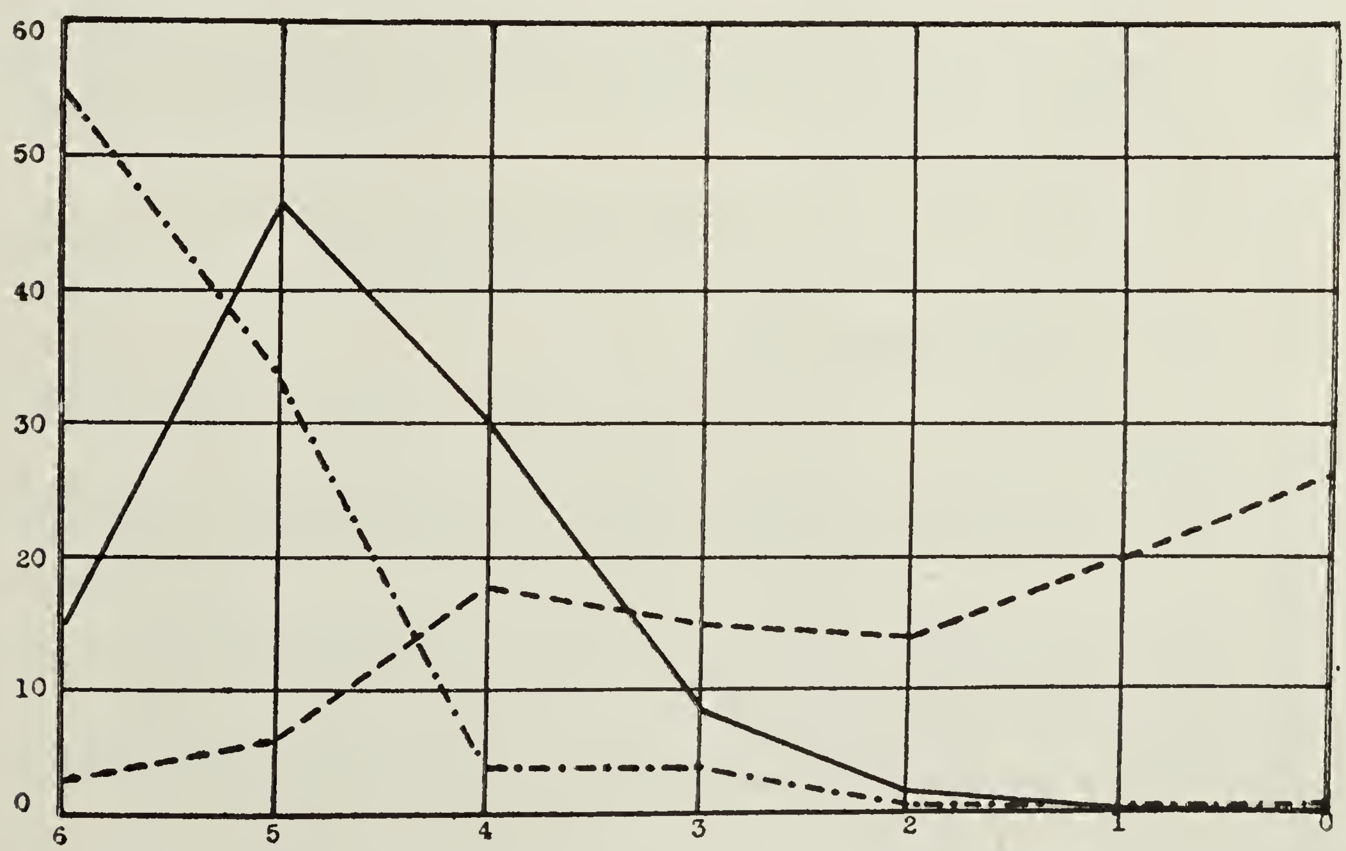

Fig. 1. Distribution of Ratings in Tonal Auditory Imagery. Solid line, unselected adults and children; dot-dash line, musicians; dash line, psychologists. Figures at the left, per cent of cases; at the bottom, vividness of the image.

themselves 6 in the second test. Only a very small percentage graded themselves below five. Some of the comments follow:

"For both tests, I cannot conceive of less than 100% for any composing musician."

"The image is as vivid as perception, but different. The pleasure of the physical shock of the vibrations is lacking."

"In these grades I have assumed that your grade 6 was impossible, as it is inconceivable that the presence of an external stimulus should not intensify the image."

"Melody, 5; piano tone color, 2; awkward to hear without image of the words."

"Melody and harmony are both imaged mentally."

"I hear America chorally—piano as accompaniment in harmony only. Hear the soprano in fourth phrase very distinctly."

"Just how to grade my own degree of auditory proficiency I hesitate to state. As regards 'America,' ear, eye, hand, and key-board are so clearly associated mentally that the auditory image cannot stand alone, although of course that was the first in conception."

"I can hear America best by hand, but find no difficulty in making myself hear it on the piano."

"I find the melody perfectly distinct, the bass not so much so, and the alto and tenor lose more or less in a change of chord rather than in distinct imagery as to their movement. I should rate myself if I understand your scale as between two and three."

"I can hear in my imagination America as played by a piano or by any one or combination of orchestral instruments, or by any voice with which I am acquainted. I should not consider that a man had any real musical gift unless he should do this."

In the composing of the melody in Test 2, some of the composers found that the grade varied with the voice for which the melodies were intended.

"4 to 6, depending on singer in mind. I tried it with four singers equally well known."

"Although I am able to image the melody up to a rating of 5, I find myself much less clear in the endeavor to conceive of it in the voice of this special person."

"5 for my own voice; 4 for soprano, bass, etc., timbre generally; 2-3 if I imagine it sung for instance by Caruso or other specific person whose voice I remember or thought I remember."

"During one year I wrote twenty-five songs for a certain baritone and when writing I always heard his voice distinctly."

In answering the first question, "Do you naturally recall music vividly in realistic auditory imagery?"—the musicians replied almost unanimously in the affirmative. There were only three doubtful replies. Some musicians recall all music vividly, others only familiar music. A few note the dependence of the auditory image in recall upon such factors as rhythm, volume, timbre, or phrasing.

The second question was: "Do your compositions always come naturally to you in realistic auditory imagery?" As a matter of fact, we have no means of knowing how many of these musicians compose, although we do know that a few of them are well-known composers. A large number did not reply to this question. Thirty-one answered yes; 1 answered no; 6 replied "not always." Of these 6, 3 noted the use of an instrument in composing. There were two exceptions to the answer yes. The first was, "except intricate passages;" the second, "occasionally a phrase end is vapory." Five musicians replied that themes come to them in auditory imagery, but details of structure and harmony do not; two could not image their compositions completely.

Other replies were as follows:

"In the composition of a melody when this is finished, it is almost as clear as when it is played, but anything to be played I usually work out and change around a great deal."

"I am not a composer, but am in the habit of extemporising. I know (grade 4) mentally beforehand what I am going to play, because I think melodically and harmonically."

"Very naturally. Melodies once started in my imagination flow along much faster than I can record them. Harmonies equally so."

"Prof. F is a composer of considerable ability. . . . He tells me that he always composes in auditory terms and without the use of a piano, even where he is composing music for an orchestra. If there is anything unusual at any point in his composition he reports that he will pause to visualize the notes as they would appear when written. But both the visualization of the notes and the actual playing of the piece once composed he considers to be translations from the original auditory images in terms of which his productions are composed. He feels quite certain that both in imagining a certain musical phrase and in composing one originally his imagery is fully as clear as in actual hearing."

"When twenty-five years of age I was operated on and remained two weeks in the hospital. During that time I conceived and completed an orchestral composition, even to every detail of scoring, including bowings, etc., which

I wrote without difficulty and without recourse to an instrument as soon as I could sit up. My first hearing of even a tone of this work was at a subsequent orchestral rehearsal previous to a performance. The success of this composition was in a large degree responsible for certain material advancements which came shortly afterward."

Of the musicians who replied to question No. 3, 59 said that their imagery had developed. Some of these gave as reason for its development their constant practice or training in music. The imagery of four had remained stationary. One replied, "I find it as strong now as it was twenty years ago." Another said, "The tendency is to regress unless constantly exercised." Some attributed the apparent development in imagery to better knowledge of how to use it, or better mental organization, or wider scope.

In regard to differences in the imagery of pupils, there was almost unanimous assent that the difference was great. There were two, however, who replied that, though there was a difference in pupils in this respect, it was not a great one.

Question No. 5 is closely connected with question No. 4. There was a large variety of answers depending on the way in which the musicians understood the question. Some referred the differences to the basis of auditory imagery; others to its connection with other phases of musical ability, and others to its importance in musical talent and education. Eight musicians based good auditory imagery or the lack of it on early training; nine on innate musical endowment; fourteen on both inherited ability and training. Only one replied that the difference was of no importance. One based the difference on general intelligence. He says: "Given two people of equal musical ability, the one who is the more intellectual will have the keener sense of auditory imagery."

The following answers show further the various opinions of musicians in regard to the significance of the auditory image.

"The indication of more or less dullness of tonal sense affecting this keenness of perception of values of various kinds."

"Without considerable such ability, I feel that the student must fall short of any really musical attainment."

"Greatest significance. Individual conceptions of music depend entirely on ability to think music."

"Vivid auditory imagery would seem to mark the musically sensitive."

"The difference shows the degree of true musicianship."

"I believe a clear auditory imagery is the real basis of musicianship."

"I consider distinct and definite auditory imagery very important. I strive to develop it in my pupils. With its development comes greater technical accuracy and better interpretation."

"Auditory imagery is a necessary factor in the higher appreciation of musical effect."

"The quality of the musician and the soundness of his aesthetic judgment depend, it seems to me, in large measure on his subjective audition."

"Significance attached to such differences depends upon whether the student has talent (a supposed talent) for composition or whether he is merely an interpreter. In the latter case, mostly lack of training (if deficient in it) and can easily be developed. In the former, it makes for sureness of touch, sureness in transcription of ideas. Sometimes coupled with unoriginality."

"The more musical pupils have the clearer image."

"I aim at the auditory image from the start. Those having clearest imagery perform most artistically and only as they gain this ability, is music of real cultural value."

"Those who are strong on imagery memorize easily."

"(1) Some students are more awake to musical impressions than others. (2) Students differ in self-consciousness and the less self-conscious they are, the freer they are to hear the music mentally. (3) Often, lack of fundamental training clouds the clear musical perception, but it can even then be brought out, under right conditions."

"The average student who is in a grade above the first seems to have imagery which I should rate 3 or 4 when dealing with music previously practiced. But the same pupils, when they are asked to write harmony exercises in class, away from the piano, frequently show inability to hear a melody alone, to say nothing of harmonic progressions. To me this seems to be a deficiency in both the imagination and memory. None of them ever write tonal combinations they have not repeatedly heard, so I should count them deficient in both respects."

"Those who have it not should desert music at once."

"The matter of tonal imagery is a vital one in musical training and education. Together with the ability to hear tones and sense rhythms through the eye while looking at symbols, this power of mental hearing is fundamental and absolutely vital in music education, not only for the singer, the player, and the composer, but for the intelligent listener as well."

"I have laid stress with my pupils upon developing auditory imagery and urge them to study new pieces away from the piano at first."

"This habit of hearing mentally I do not consider as being anything remarkable and I believe any one of ordinary intelligence can learn to do it if he is properly taught. I am constantly training students to analyze musical compositions through the ear, also to write what they hear. This is merely learning to think in the language of music, and as the musical gift is as widely distributed as any other, I am of the opinion that out of a hundred people selected at random as many could be made into successful musicians as into mathematicians or linguists."

"I consider the development of this faculty a highly important function of musical education which has been woefully neglected thus far. True, our present form of education and the hearing of good music train this faculty as a sort of by-product, often considered as an undesirable acquisition in the matter-of-fact world. But it is of inestimable value both to the composer and interpreter, especially of the larger forms. And to the non-professional musician, it is a constant source of enjoyment and inspiration.

"You have found probably the weakest spot in present-day musical training. I think nearly all children possess the faculty in rudimentary form, with great possibilities of development; but the training should begin early, and continue throughout the entire course. The results would be manifold: (1) More composers and better (it would not create geniuses, but help even them); (2) Better interpreters; (3) More intelligent listeners, whose enjoyment of music would not only be heightened, but prolonged."

B. Psychologists

In order to institute a rough comparison of the artistic with the scientific mind in this respect, the same questionnaires were sent to two hundred members of the American Psychological Association, with the request that they try the tests and record their grades. Test 2, for composition, was omitted. The dotted line in Fig. 1 gives the curve of distribution for the ninety who replied. A relatively large proportion graded themselves 0. Accompanying introspective notes usually give as a reason for the low grade in auditory imagery the prominence of kinaesthesis. Some comments of those who grade themselves 0 are as follows:

"I am predominantly of the motor type. If kinaesthesis is inhibited, I totally lack auditory imagery (whence my report of 0); if it is not inhibited I have first auditory-verbal-motor images of the words of America, estimated as '2' on your scale. Do not under any conditions get an auditory image of the tune. That is entirely carried in kinaesthesis."

"I get considerable satisfaction from rehearsing America, for I can feel the rhythm and the rise and fall of the air, and yet I doubt if I hear the imaginary music at all when I don't hum or keep time with my breathing or other muscular movements. When I let myself go, even without humming, I find it exciting, but I doubt if I *hear* it at all."

"Personally my most vigorous efforts with the most familiar songs give me the very faintest image of the sound, which I refer to muscular effort to repeat the sound."

"I showed your paper to a well-known pianist here and he made the comment that in his own case the mental image was clearer and more satisfactory in some instances than the direct sensation, so that he thought there was one degree beyond your maximum which had to be taken into consideration."

"My musical imagery is vocal. I do not have auditory imagery at all."

"Even after I have heard a selection scores of times, I seldom recognize it. When I do recognize it, the reason is that I get the rhythm, not the sounds. Many of the sounds might be changed and if the rhythm were kept constant I would not realize any difference."

"I have no voluntary control over my auditory imagery. Ordinarily they rank in vividness about 2. Occasionally a melody perseveres for a long time at a clearness of 3 to 4. I do play the piano, but had also several years training in violin and pipe-organ, besides considerable voice-training. But am a very poor singer. Have composed several pieces (none published). Had instruction in musical theory, composition and orchestration. Nevertheless, I have never learned to depend upon my auditory imagery, presumably it was never pointed out to me. When playing from memory I depend exclusively upon kinaesthetic process."

"Clear image of phrase *as sung by self*—can get no other."

"I have no musical ability. I am unable to carry a tune although I do not sing in monotone. I am told, however, that I am usually out of tune when singing with a congregation. It seems that I am particularly deficient in auditory imagery. Strange as it may seem, I am extremely fond of both concert and vocal music and thoroughly enjoy grand opera and recitals. However, I have never had any melody or tune run through my head. I dream frequently but never so far as I can remember have I ever heard a voice in my dreams."

"I never have anything but the faintest auditory imagery. Kinaesthetic sensations of tensions in ear or larynx seem to take their place with me."

"I can get a clear image of the tone of any instrument or voice, only when I aid my imagination by actual movements of the vocal chords."

"I occasionally have pure auditory images, especially hypnagogically; but even these are rare. They are also fairly clear during perseveration, but this I have not treated for your purpose. I cannot now, in making these tests, secure your auditory images without kinaesthetic support."

"I had a very clear and distinct vocal motor auditory image of my own voice *singing* America, but I could not get an auditory image of this air as played on a piano. I made several efforts, and even went so far as to visualize a person—twice a woman and once a man—sitting at a piano, but I could not get the faintest image of a piano note."

Two psychologists who grade themselves 1 write as follows:

"Mine are almost wholly muscle-memories, lodged seemingly in the throat, mixed with visual memory of the musical scale, a crowd singing, etc."

"I feel sure that I have very faint auditory imagery, if, indeed, I have any at all. I find myself trying to respond to your experiments emphasizing always certain motor processes rather than the auditory results. Whenever I think of a melody which I know I began to think of this melody in terms of the way in which I should produce it rather than the way in which I hear it. Such auditory imagery as I can trump up seems to be very transient. It comes in spots and then disappears. It cannot be sustained for any length of time and hence my skepticism about its existence at all."

There are also a number of other introspective notes which analyze the auditory complex:

"Never quite certain that the clearness of the auditory image is not in part due to voco-motor re-enforcement."

"I have given myself a grade of 1 in your first test, because I get a fairly clear auditory image of the opening chord of America as played on the piano, but cannot get any of the succeeding notes without hearing also a fairly clear chorus of voices singing and having the piano drop to a rather droning accompaniment. Images in both tests are accompanied by visual images (grade 6) and distinct kinaesthesis. You may also want to know that I cannot "carry a tune" unless I can "follow along" with some one else. If I try to sing alone, I generally know when I am "off," but often cannot say whether I flat or sharp."

"In both cases the tune was a perfectly definite fact. It could not possibly be confounded with any other tune or with anything else in the world. Yet the sensory factors seemed very elusive."

"I cannot eliminate the voice accompaniment. In both tests, a great deal of organic and kinaesthetic material present which I am afraid gives me the auditory attitude and meaning without true auditory "content" of the type asked for."

"I find motor images from tongue (and possibly vocal organs) for the minor rhythm and from the head or some larger body mass for fundamental rhythm. Without these images are much less vivid."

"Extending the experiment, I find the imagery clearer for specific voices than for specific instruments."

"I am passionately fond of music and have played a pianola for several years. In this way I have trained my ear so that I can carry melodies or motives from Beethoven or Chopin in my memory. This perhaps has something to do with my relatively prominent auditory imagery." (Grades 5 and 4)

"My grade of 1 is due to the fact that I never listen to the piano accompaniment of America, and I never have heard the piano alone with that melody. Had you asked for voice or voices the grade would be 5."

"The auditory image is very clear and focal. The timbre of the imaged tones, however, is rather indistinct and undifferentiated (i.e., I should not recognize immediately as of the piano quality). Besides the auditory image, there is present also fairly clear (3) vocal-motor imagery of slight tension in the throat muscles and very clear (5) kinaesthetic imagery of lip and tongue movement (somewhat as though whistling). In my customary imagery of musical phrases this kinaesthetic imagery almost invariably amounts to slight actual innervation."

"It seems to me that the imagery which arises when making the test is not a single thing or even a compound of fusible parts, but rather consists of distinct parts of varying degrees of clearness. For instance, the rhythm, that is, the rate and duration, of the different tones is very clear; but the tonal quality is very faint indeed if it exists at all. The tones seem to be represented by a sort of kinaesthetic image. The higher tones by a sort of tensing of muscles of neck and cheeks. If it is inhibited here, it seems to break out in some form of gesture imagery."

"In test 1 motor imagery of the words as sung by myself and auditory imagery of the words sung by myself interfered. I could hear the piano faintly but the other images predominated." (Grades 2 and 4)

"Auditory imagery attended by kinaesthetic processes (throat and hand) and very clear visual imagery. Auditory imagery of other melodies (sound or piano) is clearer. I last heard America from the phonograph."

"I do not know any music. I have never memorised tunes. I have clear images of sound. I can hear a whistle or organ or orchestra in imagination quite clearly."

"Found test 2 to involve (a) visual imagery; (b) auditory imagery; (c) invention; (d) memorization and in my case predominantly motor and kinaesthetic imagery. All this complexity gave an almost negligible auditory imagery, viewed alone."

"Test 1. I am very certain that I did not hear in my imagination the whole phrase from beginning to end. I seem to be able to catch the beginning of it, say three or four notes; the remainder of the phrase I was totally unable to identify even when the greatest effort to do so prevails. In fact I find it necessary to visualize the piano and some one at it in order to get the first part of the phrase in tonal images.

"Test 2. The high grade 3 here I think is due to the fact that I put the phrase of my invention into the mouth of my mother, who used to sing a great deal and who still sings some. It must be of interest to you to know that when I put the same phrase into the mouth of any one of half a dozen persons I am scarcely able to get any imagery."

"My auditory imagery is very clear, and I habitually have musical images that are almost as clear as actual hearing. But these images are not subject to voluntary control, and my reaction on the tests is therefore unsatisfactory.

"Although I have no technical ability, I am more deeply moved by music than are some professional musicians of my acquaintance.

"Imagined music is a very important factor in my daily life. Musical images are almost present in consciousness. I can banish them only by straining my attention on something else, and then only for a moment. It is very difficult to effect a substitution of a desirable melody for an undesirable one. I may be annoyed for many days by a rhythmical air that I have heard on the street. At other times I hear in imagination the symphonies of which one never tires. The harmony is present in all its richness, and I can hear distinctly each instrument of the orchestra.

"Drowsiness is conductive to heightened activity of my musical imagination. I may waken in the night with a clear image of a melody which I have heard but once, possibly years ago. I go over it repeatedly, trying to hold it until I can identify it but it is usually gone before I am sufficiently wide awake to write down any part of it."

The lower grades of the psychologists represent not only differences in imagery, but also differences in methods of evaluating it. The psychologists analyze their mental content critically, and find other factors in connection with their auditory images.

It is probable that practice in introspection always reduces the imagery grade somewhat. The writer finds that her own average grade dropped with extensive practice from 5 to 3. Introspective notes show, however, this is not the sole element, but that actual differences exist in imagery not only between the musicians and psychologists, but among the psychologists themselves.

C. *Children (unselected)*

Test 1 was given to 1,444 grammar school children, unselected and almost evenly distributed in the four grades. The distribution for these is shown in the dark curve, Fig. 1. The same test given to university sophomore girls yields a distribution for these adults which is practically identical with the distribution for grammar school children.

Taking the curve for unselected children and adults as a basis for comparison, we see in the other two curves an unmistakable divergence of the musical and the scientific minds from this. Is this divergence a ground for the selection of occupation, or is it the result of occupation?

The crudeness of this method of investigation is frankly admitted. Yet it is introspective facts that we seek. They were gathered without prejudice. The testimony here gathered is rich in suggestiveness, and should lead to controlled investigation of the numerous problems raised.

THE AUDITORY IMAGERY OF GREAT COMPOSERS

By

Marie Agnew, Ph.D.

In order to study the imagery of composers, a number of letters and autobiographies of great composers were examined. The purpose was to find the type and characteristic features of their imagery, to determine whether the imagery was a necessary part of their musical genius, and whether they used it in composition. The original intention was to make a statistical collection, taking ten composers, and giving their statements in regard to their imagery, accepting as evidence only those quotations which showed unmistakably the presence of imagery. However, this was found to be impracticable. It was difficult to get complete accounts of a composer's musical experiences and his method. Often there was no material. Again, material which would have been serviceable had been inadvertently destroyed, as was Schubert's diary. Even available material was often unsatisfactory. Some of the composers were not introspective, and recorded their composing in a matter-of-fact way, or gave any scattered references to their musical imagery. They did not have the psychological concept of the image. In fact, some of them had not the opportunity, as they lived before the psychology of the image developed. The result was that they recorded musical experiences in a naïve way.

To show a characteristic rôle of imagery, extracts may be made from five musicians,—Schumann, Mozart, Berlioz, Tschaikowsky, and Wagner. These were selected because they were the most outspoken, and have expressed clearly the character and function of their auditory imagery.

Schumann

Schumann's imagery was remarkably realistic in character. It was so vivid that he retained tones in almost their original clearness long after he had first heard them. His imagery was not only vivid, but accurate and profuse. When listening to piano music, he could fill it in with the tones of other instruments, hearing it as though played by an orchestra.

His auditory imagery was the most important factor in his musical genius. He composed through his "inner hearing." He advised other composers to eschew the use of an instrument and to compose with the aid of their mental images alone. In interpreting, he imagined the effect he thought the composer wished to produce. He urged conductors to hear their music in imagination the first time from looking at the written score of the separate parts. He himself criticised music he had never heard by playing it in imagination from the score.

Although Schumann's imagination was predominantly auditory, he also had vivid visual imagery. Often he composed with the aid of "pictures," developing them simultaneously with his musical thought. Music aroused both visual and auditory images for him, although at times the music served for the sound itself and only the associated visual images were prominent. His visual images helped to give him full settings for his music, and stimulated his auditory imagery as to completeness and profusion.

Schumann would often get totally different imaginative effects from the same piece of music. One element of charm in his essays is his expression of the distinctly different appeal of music to the three phases of his personality, which he makes entirely different, and constantly speaks of as actual "members of the Davidite society."

The following quotations show the character of Schumann's imagery and his use of it:

"For two long hours this motif rang in my ears." (II, p. 239)

"He who has once heard Henselt can never forget his playing; these pieces still haunt my memory like the recollection of a parterre of flowers." (II, p. 236)

"Our judgment concerning them must not be considered exhaustive, as we have only heard one of them performed; for though the inner musical hearing is the finer one, the spirit of realization has its rights; the clear, living tone has its peculiar effects." (II, p. 177)

"We are not able to say more, regarding a trio by C. Seyler, save what a silent performance, with the parts laid around us, will allow. It seems, however, clear enough to dispense with a score, and does not apparently rise beyond that mediocre flight of thought which may always be guessed at a few minutes beforehand; in the pauses of the pianoforte part I am nearly always able to imagine the filling out of the other instruments." (11, p. 179-180)

"I have sung the work over as finely as possible in imagination." (11, p. 450.

"If, in the very first measure I can detect the kettle-drum, the answering tutti in the second, and later on, a violin unison, the character of the instrument for which it was written is not thereby injured, but our enjoyment of it is rather heightened." (11, p. 451)

"I turned over the leaves vacantly; the veiled enjoyment of music which one does not hear, has something magical in it." (10, p. 4)

"They will be understood by those who can rejoice in music without the pianoforte—those whose inward singing almost breaks their hearts." (10, p. 263)

"He is a good musician, who understands the music without the score, and the score without the music. The ear should not need the eye, the eye should not need the (outward) ear." (10, p. 63)

"In a word, the scherzo of the symphony seemed to me too slow, the restlessness of the orchestra, trying to be at ease with it, made this very observable. Yet what dost thou in Milan care about it all? And I as little, since at any moment I can imagine the scherzo as it ought to be played." (10, p. 38)

"You think I do not like your 'Idyllen'? Why, I am constantly playing them to myself." (9, p. 293).

"Try to sing at sight, without the help of an instrument, even if you have but little voice; your ear will thereby gain in fineness." (10, 1, 410)

"Sometime I am so full of music, and so overflowing with melody, that I find it simply impossible to write down anything." (9, p. 81)

"But if you knew how my mind is always working, and how my symphonies would have reached Op. 100, if I had but written them down." (9, p. 81)

"During the whole of this letter my 'Exercise Fantastique' has been running in my head to such an extent that I had better conclude, lest I should be writing music unawares." (9, p. 177)

"The piano is getting too limited for me. In my latest compositions I often hear many things that I can hardly explain."

"Finally, as the gods have given me powers of thought and imagination, to make life brighter and happier, why shouldn't I make good use of them, instead of letting them be wasted." (9, p. 117)

"What the mere fingers create is nothing but mechanism; but that which you have listened to when it resounded within your own bosom will find its echo in the hearts of others." (11, p. 283)

"Philosophers . . . . are certainly mistaken in supposing that a composer who works according to an idea, sets himself down like a preacher on a Saturday afternoon, portions out his task in the customary three parts, and works it up accordingly. The creative imagination of a musician is something very different, and though a picture, an idea may float before him, he is only then happy in his labor when this idea comes to him clothed in lovely melodies, and borne by the same invisible hands that bore the 'golden bucket,' spoken of somewhere by Goethe." (11, p. 60)

"We advise him not to write at his instrument, but to endeavor rather to bring his forms from within than to draw them from without." (11, p. 500)

"It is a pleasant sign if you can pick out pretty melodies on the keyboard; but if such come to you unsought, rejoice, for it proves that the inward sense of time pulsates within you." (10, p. 417)

"When you begin to compose, do it all with your brain. Do not try the piece at the instrument until it is finished. If your music proceeds from your heart, it will touch the hearts of others." (10, 1. 417)

"People err when they suppose that composers prepare pens and paper with the predetermination of sketching, painting, expressing this or that. Yet we must not estimate outward influences too lightly. Involuntarily an idea sometimes develops itself simultaneously with the musical fancy; the eye is awake as well as the ear, and this ever-busy organ sometimes holds fast to certain outlines amid all the sounds and tones, which, keeping pace with the music, form and condense into clear shapes. The more elements congenially related to music which the thought or picture created in tones contains within it, the more poetic and plastic will be the expressiveness of the composition; and in proportion to the imaginativeness and keenness of the musician in receiving these impressions will be the elevating and touching power of his work." (10, pp. 250-1)

Mozart

Mozart is noted for the large perspective of his auditory imagery. When his compositions were finished, he heard them mentally as a whole, just as an artist might see in imagination a picture complete with all its details. It is perhaps due to this faculty that Mozart holds his eminent position among composers.

Mozart's musical memory was marvellous. Even when a child, he showed unusual aptitude in retaining music. It was when he was still a boy that he accomplished the famous "theft" of the "Miserere" in only two visits to the Sistine chapel. In later life he often played his own part of a composition from memory when he had written out the other parts, and had no time left in which to write his own. It is said that frequently the brass instruments had no part in his original score, and that he added these afterward on separate paper, carrying the other parts in memory (7, p. 298).

Mozart attributed this wonderful memory to his auditory imagery. Holmes, his biographer, also testifies to the importance of his imagery. He tells us that at six, Mozart composed in mental music without the aid of an instrument, and that "his power in mental music constantly increased, and he soon imagined effects of which the original type existed only in his own brain" (7, p. 13).

So prominent was Mozart's auditory imagery that he habitually translated his impressions from other senses into auditory terms. For this reason, fine scenery always stimulated his imagination, and he composed at his best when out-of-doors.

Mozart's auditory imagery was well supported by kinaesthetic imagery. He also hummed or sang his musical ideas at their inception.

Mozart tells how he composed as follows:

"When I am, as it were, completely myself, ... my ideas flow best and most abundantly. *Whence* and *how* they come, I know not, nor can I force them. Those ideas that please me I retain in memory and am accustomed, as I have been told, to hum them to myself. If I continue in this way, it soon occurs to me how I may turn this or that morsel to account so as to make a good dish of it, that is to say, agreeably to the rules of counterpoint, to the peculiarities of the various instruments, etc.

"All this fires my soul, and, provided I am not disturbed, my subject enlarges itself, becomes methodized and defined, and the whole, though it be long, stands almost complete and finished in my mind, so that I can survey it, like a fine picture or a beautiful statue, at a glance. Nor do I hear in my imagination the parts *successively,* but I hear them, as it were, all at once (*gleich alles zusammen*). What a delight this is I cannot tell! All this inventing, this producing, takes place in a pleasing, lively dream. Still, the actual hearing of the *tout ensemble* is, after all, the best. What has been produced thus I do not easily forget, and this is perhaps the best gift I have my Divine Maker to thank for.

"When I proceed to write down my ideas, I take out of the bag of my memory, if I may use that phrase, what has previously been collected into it in the way I have mentioned. For this reason, the committing to paper is done quickly enough, for everything is, as I said before, already finished, and it rarely differs on paper from what it was in my imagination." (7, pp. 329-30)

Berlioz

Berlioz was extremely sensitive. Sense perceptions stimulated him in romantic emotionalism or to nervous frenzy, according to their character. This sensitivity is the index of Berlioz's imagination, which was vivid, realistic, and fantastic. At times his imaginative fancies made him morbid; at others, wildly joyful. Berlioz heard his compositions mentally. He objected to the use of any instrument in composing, dubbing the piano the "grave of original thought." Not only did he hear his own compositions in tonal imagery, but he imagined the productions of other composers, and was sometimes disappointed in their performance.

His themes came spontaneously. Very often he dreamt them, and wrote them down on awaking. In his voluntary quality, his auditory imagery was like Mozart's.

In the following extracts, Berlioz shows how he used his auditory imagery in composing:

"If I had any paper I would write music to this exquisite poem; I can *hear* it." (3, p. 117)

"Two years ago, when there were still some hopes of my wife's recovery, ... I dreamt one night of a symphony.

"On awakening I could still recall nearly all the first movement, an allegro in A minor. As I moved towards my writing-table to put it down, I suddenly thought:

"'If I do this, I shall be drawn on to compose the rest. . .' With a shudder of horror, I threw aside my pen, saying:

"'Tomorrow I shall have forgotten the symphony.'

"But no! Next night the obstinate motif returned more clearly than before —I could even see it written out. I started up in feverish agitation, humming it over and—again my decision held me back, and I put the temptation aside. I fell asleep and next morning my symphony was gone forever." (3, p. 225)

"Last night I dreamt of music, this morning I recalled it all and fell into one of those supernal ecstasies. . . . All the tears of my soul poured forth as I listened to those divinely sonorous *smiles* that radiate from the angels alone. Believe me, dear friend, the being who could write such miracles of transcendent melody would be more than mortal." (3, p. 232)

Tschaikowsky

The chief characteristic of Tschaikowsky's imagery was its marked spontaneity. His musical themes came to him not only voluntarily, but forcefully, with a compelling power. They welled up from within with inconceivable force and rapidity, throwing him into a condition which he called *somnambulistic,* in which "the soul throbs with an incomprehensible and indescribable excitement, so that almost before we can follow this swift flight of inspiration, time passes literally unreckoned and unobserved."

Tschaikowsky's imagery had had the same compelling quality when he was a child. At four, his governess once found him crying long after the other children had gone to sleep. There was no music going on at the time, but when she asked him what was the matter, he replied, "Oh, this music, this music! Save me from it! It is here, here," pointing to his head, "and will not give me any peace" (14, p. 13). His brother says that, very early, "musical sounds according to his own account, followed him everywhere, whatever he was doing" (14, p. 18).

Fullness and exuberance also characterised Tschaikowsky's imagery. The melodies of his compositions never came to him singly, but in complete form, fully harmonized. The basis of his vivid, profuse imagery was a keen sensitivity. He was deeply affected by nature, and responded to it much as did Wordsworth.

In regard to the function of Tschaikowsky's auditory imagery his brother says that "whenever Tschaikowsky wrote a symphonic work, he already heard it in imagination as it would sound in the concert-room at Moscow" (14, p. 409). Tschaikowsky himself describes minutely his method of composing, showing the part played by the auditory image. In particular, he notes the effect of distraction—how sounds intruded on his mental music, and broke off the thread of his inspiration.

"It would be vain to try to put into words that immeasurable sense of bliss that comes over me directly a new idea awakens in me and begins to assume definite form. I forget everything and behave like a madman. Everything within me starts pulsing and quivering; hardly have I begun the sketch ere one thought follows another. In the midst of this magic process it frequently happens that some external interruption wakes me from my somnambulistic state: a ring at the bell, the entrance of my servant, the striking of the clock, reminding me that it is time to leave off. Dreadful, indeed, are such interruptions. Sometimes they break the thread of inspiration for a considerable time, so that I have to seek it again." (14, p. 274)

"You ask me how I manage my instrumentation. I never compose in the *abstract*; that is to say, the musical thought never appears otherwise than in a suitable external form. In this way, I invent the musical idea and the instrumentation simultaneously. Thus I thought out the scherzo of our symphony—at the moment of its composition, exactly as you heard it. It is inconceivable except as a *pizzicato*. Were it played with a bow, it would lose all its charm and be a mere body without a soul." (14, p. 281)

"I usually write my sketches on the first piece of paper to hand. I jot them down in the most abbreviated form. A melody never stands alone, but invariably with the harmonies which belong to it. These two elements of music, together with the rhythm, must never be separated; every melodic idea brings its own inevitable harmony and suitable rhythm." (14, p. 309)

"Began the fifth scene, and in imagination I finished it yesterday, but in reality only got through it early today." (14, p. 602)

"Yesterday, on the road from Voroshba to Kiev, music came singing and echoing through my head. . . . A theme in embryo, in B major, took possession of my mind, and almost led me on to attempt a symphony." (14, p. 140)

"During my journey, while composing it (a symphony) in my mind, I frequently shed tears. Now I am home again, I have settled down to sketch out the work, and it goes with such ardour that in less than four days I have completed the first movement, while the rest of the Symphony is clearly outlined in my head."

"All day long this duet has been running in my head, and under its influence I have written a song, the melody of which is very reminiscent of Massenet." (14, p. 383)

Wagner

Wagner seemed to have apprehended more than any other composer the psychological concept of the image. He speaks of visualizing scenes and characters and he frequently uses the word image in much the same way as it is used in modern psychology. The following extract shows his use of it:

"My whole imagination thrilled with images; long-lost forms for which I had sought so eagerly shaped themselves ever more and more clearly into realities that lived again. There rose up soon before my mind a whole world of figures, which revealed themselves as so strangely plastic and primitive, that, when I saw them clearly before me and heard their voices in my heart, I could not account for the almost tangible familiarity and assurance in their demeanor." (15, p. 314)

It is possible, indeed, that Wagner gained his concept of the image through contemporaries. He lived during the time when Galton was making his researches on imagery, and may have been familiar with Galton's work. Further, he was an omnivorous reader and was inordinately fond of philosophy. Either directly or through the work of German philosophers, he may have become acquainted with the notion of the image which was set forth by Hobbes and the other English empiricists and which was the forerunner of the present day concert. He may also have known of the work of Taine. His comments on Kant, Schopenhauer, and Fuererbach suggest a knowledge of scientific psychology.

Wagner's imagery was unusually persistent. Operas which he conducted often haunted him so long as to be extremely disturbing. The shouting of the Dresden revolutionists "re-echoed in his brain" for several days.

Wagner's visual imagery was co-ordinate with his auditory imagery. He visualized scenes and characters for his operas at the same time that he heard the music for them in imagination. In listening to music, he lived in a world of mental sounds and related pictures.

Although the composers differ in the pattern of auditory image complex, they have certain features in common. The artistic type of mind is extremely sensitive. Insignificant stimuli often produce on the artist entirely disproportionate effects. Nature in all its aspects gives him keen sensory enjoyment. This sensitivity parallels vivid imaginative power.

Spontaneity of imagery is also characteristic of the composer. His themes "occur" or "come to" him, or are the result of an "inner impulse." This voluntary quality of images is due to the conscious maturing of thought, through mental saturation with sound images.

A PURSUIT APPARATUS: EYE-HAND COÖRDINATION

By Wilhelmine Koerth, M.A.

The instrument described in this article was designed with the coöperation of Dr. Seashore to measure capacity for the acquisition of skill in coördination of eye and hand. The Miles'[1] Pursuit Pendulum suggested the use of a moving stimulus following a fixed path at a constant speed as a convenient method of measuring eye-hand coördination; and this principle was incorporated in a simple, readily portable, and inexpensive apparatus. In the form as finally adopted and standardized, Figure 1, the apparatus consists of a rotating wooden disc carrying a polished target and commutator with flexible contact, a Veeder counter operated by magnets, a control key, a hinged pointer, a storage battery, and a small phonograph.

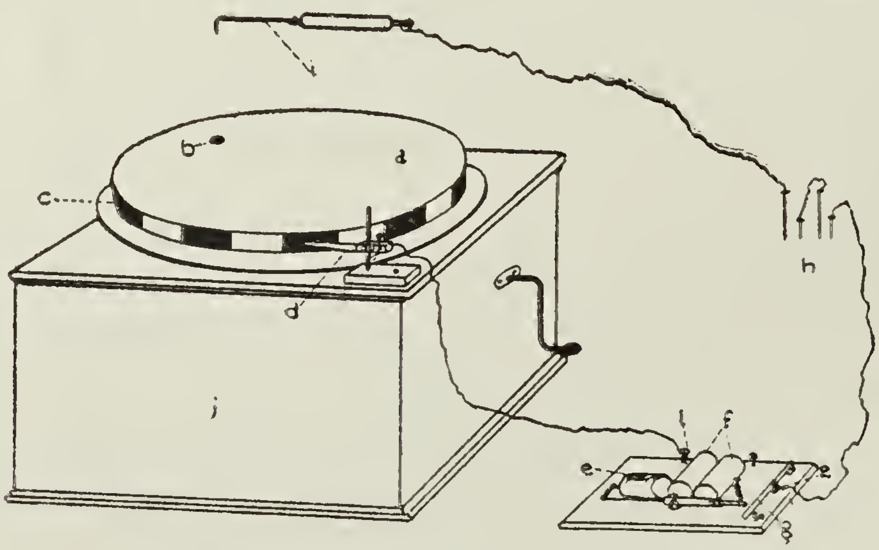

Fig. 1.—The Pursuit Apparatus: a. wooden disc, b. brass target, c. commutator, d. flexible contact, e. Veeder counter, f. magnets, g. control key, h. battery, i. hinged pointer, j. phonograph, 1 and 2 binding posts.

The wooden disc, 27.5 cm. in diameter, and 2.2 cm. thick, rests firmly on the phonograph plate, revolving with it. The brass target, 1.9 cm. in diameter, is sunk flush with the surface of the disc 8 cm. from the centre. A commutator to govern the counter

[1] Miles, W. R. A pursuit pendulum. *Psychol. Rev.*, 1920, *27*, 361-376.

is provided by ten brass plates sunk in the edge of the disc in such a way as to present a smooth surface of alternating metal and wood to a flexible contact. The plate and target are connected by concealed wires. The disc is stained dull black and all metal parts are highly polished.

The flexible contact rests lightly against the edge of the disc and is mounted so that it can be screwed to the phonograph. It consists of a tapering strip of spring brass held to a post by a thumb screw. The contact is made practically soundless by a small rubber band wrapped around it to absorb vibration.

The hinged pointer consists of a 10 cm. x 2 cm. wooden handle to which is attached, like a one way hinge a 30 gauge brass wire 13 cm. in length with 3.5 cm. of the end bent at right angles. This gives a pointer that can be held in the hand like a knife and with which no pressure other than the constant weight of the wire can be brought to bear on the target.

The Veeder counter is operated by magnets controlled by the commutator on the edge of the disc. The commutator is in circuit only when the control key is closed and the pointer is held on the target. As there are ten breaks in the commutator the counter will record in tenths of seconds the time the observer is able to hold the pointer on the moving target. A 6 or 8 volt direct current is ample to operate the counter. This can readily be supplied by a 6 volt storage battery, 4 dry cells, or any properly modified direct current.

Any phonograph using disc records can be used if it can be regulated to one revolution per second.

The apparatus is connected as indicated in Figure 1. The flexible contact (d) is connected with binding post 1 of the counter; binding post 2 with the battery (h); the battery with the hinged pointer (i). This leaves the circuit broken at control key (g) and at the pointer. The phonograph must be timed to run at the rate of 1 revolution per second.

In administering the test, the instructions are given verbally and are demonstrated at the same time. The observer is then allowed to practice for two minutes and is instructed to stop and start the phonograph several times in that interval and to speed up with the motor. When the observer fully understands what he is to do, record number in the counter, give the "ready" signal and in four or five seconds close the control key, at the same time giving the order "go." Keep the key closed twenty seconds, then release key, give order "stop," and record number in the counter. The twenty second interval is best controlled by counting the revolutions of the disc. Give five trials as rapidly as possible without hurrying, then allow a complete rest period of approximately two minutes. Proceed thus until twenty trials have been given. Record the number registered by counter at beginning and end of each trial and from this compute the record for that trial. This gives the number of tenths of seconds out of a possible 200 that the observer held the pointer on the target. To reduce the record to basis of percent divide the number computed from counter by two.

Instructions to the observer: "In this test you show your ability to learn a new movement. At first you may not be able to follow the target well at all, but as you proceed your eye and hand begin to work together and you improve much when you do your best. Hold the pointer like this:[2] Keep the wrist and pointer straight. With the body erect and well poised keep the pointer on the target like this:[2] A full easy swing of the arm from the shoulder is best. Let the other hand rest lightly on the edge of the phonograph. With the command "ready" start the phonograph, get into position, and follow the target with the pointer.[3] When the target is revolving at top speed, I will close the key and say "go." Do your best until the command "stop," then stop the machine and stand at ease until the next signal. The more completely you relax between trials the more rapidly you will learn."

The examination of the records made by 126 observers revealed various tendencies. The observers fall into four groups: those who start low and end low, those who start low and end

[2] The pointer should be grasped firmly, palm down, as one would grasp the handle of a knife with a full hand grasp. Pointer and forearm must be held as nearly in line as possible throughout the test.

[3] Tell the observer to begin practice here, and give last part of instructions just before beginning the real test.

high, those who start high and end higher, and those who start fairly high and show comparatively little improvement. The fourth type is not as well marked as the others and could, perhaps, be grouped with the other types. No observer failed to make progress. Comparison of individual trials in each group of five also shows characteristic types of observers. There were those who started the group low and "warmed up" to a high score at the end, those who reached high score the third trial and slumped in the fifth, those who started high, slumped in the third and recovered again in fifth, those who started high and decreased to the last trial, those who maintained the same level, and those who showed no consistency in their performance. These individual trials gave in many cases a more significant index of the observer's nervous stability than can be secured from the averages. No intensive study was made, however, of the significance of the individual trials.

The curve of distribution tends to be normal if the averages

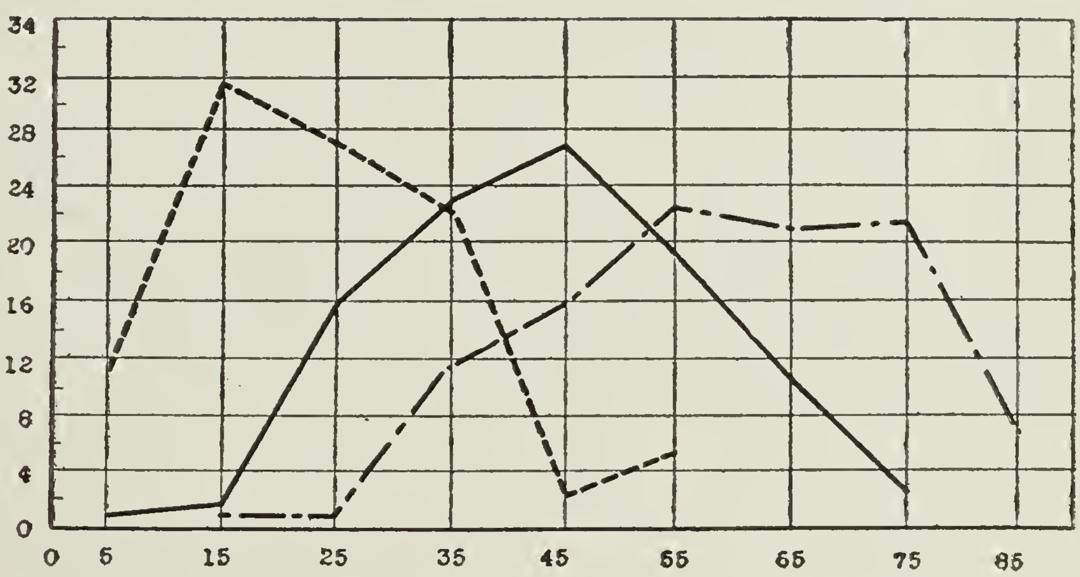

Fig. 2.—Distribution Curves: solid line for 20 trials; dash line for 5 trials; dot-dash line for last 5 trials. Figures at bottom per cent of time pointer was held on target; figures at left, per cent of cases.

of the twenty trials are taken, the mode falling at 45 and the extremes at 5 and 75. When the averages of the first five trials are taken the curve skews to the left, and with the averages of the last five trials the curve flattens and skews to the right as shown in Figure 2. Norms constructed on these data are shown in Fig. 3.

Typical learning curves were obtained in ten practice periods.

In the twelve cases studied those who began high and ended high and those who began low and ended high on the first twenty trials made better scores at the end of the periods than those

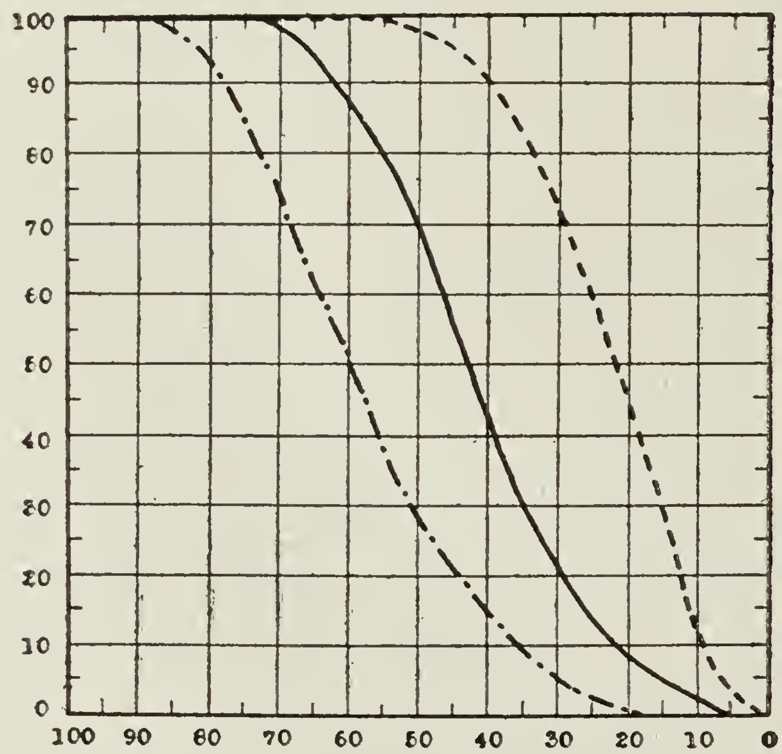

FIG. 3.—Norms: solid line, average of 20 trials; dot-dash, average of first 5 trials; dash, average of last 5 trials. Figures at bottom, per cent of time pointer was held on target; figures at left, percentile rank.

who began the first twenty trials low or only fairly high and showed little improvement. On the whole there is some evidence that a high score at the end of the first twenty trials is prognostic of ultimate skill, but more cases must be studied before definite conclusions can be drawn.

THE TAPPING TEST: A MEASURE OF MOTILITY

by

MERRILL J. REAM, PH.D.

CONTENTS.—*Previous uses of the tapping test; the present problem; apparatus; method of procedure (type of movement and positions in performance, arm position in tapping, finger positions in tapping, the length of the tapping period, the optimum number of trials, directions for giving the test, sources of error in tapping, the effect of practice on the tapping rate, rates and norms); age and sex differences; relevant correlations; factors conditioning rapidity of performance in tapping, application and future experimentation; bibliography.*

Previous uses of the tapping test

The tapping test has had a long history in experimental psychology. There has accumulated a great variety of methods of procedure which the standardizer must investigate one at a time. This diversity of procedure is accounted for by the almost endless array of uses to which the test has been put. Some of the principal ones have been:

(1) A part of a general ability scale for school children. Kirkpatrick (26), Pyle (34), Bickersteth (4).
(2) Part of a scale of tests for adolescents. Woolley (56).
(3) Part of a scale of tests for college freshmen. Bingham (7).
(4) A measure of sex differences. Burt & Moore (11), Thompson (43).
(5) An index of voluntary motor ability. Gilbert (17), Dresslar (14).
(6) An index of native rapidity of movement. Bryan (10).
(7) A measure of the duration of the contraction and of the relaxation of a movement. Franz (16).
(8) An index of right-handedness. Wells (50), Bolton (9), Bryan (10).
(9) The effects of cross-education. Davis (13).
(10) An index of fatigue. Gilbert (17), Kelly (24), Wells (47), Thompson (43), Moore (32), Johnson (23), Trace (44).
(11) The effects of practice and warming up. Wells (48), Stecher (41).
(12) One of a series of tests of working efficiency with reference to
 (a) The effect of caffein. Hollingworth (20).
 (b) The effect of alcohol. Hollingworth (22), and Poffenberger.
 (c) The effect of restricted diet. Benedict, Miles, Roth, and Smith (3).
 (d) The effect of humidity. Stecher (41).
 (e) The effect of loss of sleep. Gilbert and Patrick (33).
 (f) The effect of dental treatment on school children. Kohnky (27).
 (g) The most efficient working period of the day. Marsh (31), Hollingworth (21), Stecher (41).
(13) A test for the selection of employees (shell inspectors). Winchester Arms Company (29).

(14) A measure of occupational efficiency in hand sewing. Hollingworth and Poffenberger (22).
(15) The motor effects of nervous and mental disease, particularly mania and melancholia. Franz (16).
(16) The effect of attention on the maximum rate of voluntary movement. Effect of distractions. Bliss (8).
(17) The relative rapidity of movement of different body joints. Bryan (10).
(18) The relation of physical ability to mental ability at large. Bagley (2), Bolton (9).

The present problem. The present problem is, in general, to measure a basic motor capacity; in particular, the problem is to plan a test which will call into play a simple repeated movement, fundamental, native in character and easy to measure, and which will *not* call into play accessory, coördinated, and learned movements. This fundamental capacity for speed in a simple repeated movement we call *motility.* It has usually been known as *motor ability.*

As a measure of motility, the tapping test has the following advantages: it is one of the most objective that can be applied; the test is simple, easily given, and quickly learned. It has the advantage of readily stimulating the observer.

In the standardization, the idea of general use was continually kept in mind, so at all times a standard commercial article or piece of apparatus was chosen over a highly technical piece of laboratory apparatus, provided such a preference involved no sacrifice of accuracy in the test. Another guiding principle has been that there is no need for further refinement of procedure, recording instrument, or timing device than the variability of the test justified. For example the least variation of a single trial of five seconds from another trial would be one tap, or approximately .12 of a second. The latent time of the electromagnet was found to be approximately .003 of a second on the make. So for all practical purposes of the test this latent time could be entirely disregarded.

Apparatus

The tapping instrument. The ordinary telegraph key has been used as the tapping instrument by Wells (47), Bagley (2), Davis (13), Dresslar (14), Link (29), Smith (39), and Woodworth (54).

The tapping board and stylus, fully described by Whipple (51), was the instrument chosen by Hollingworth (20), Marsh (31), Stecher (41), Whipple (51), Woolley (56). Von Kries (45) has a very similar device, a wire attached to the finger with which the observer taps on a metallic plate.

The method of pencil dots on paper was employed by Binet and Vaschide (6), Franz (16), and Burt and Moore (11). Essentially the same was the making of pricks in paper with a pointed stylus used by Abelson (1) and Burt (11). This method, modified slightly by making small vertical lines on paper, was used by Kirkpatrick (26) and Franz (16).

Scripture and Moore (36) used a thumb and finger key, with two slides; the thumb slide held stationary and the finger slide movable. Trace (44) used a heavy resistance thumb and finger key. Similar to this was a finger movement, directly recorded on a revolving drum by means of a marker attached to the finger, the method of Benedict, Miles, Roth and Smith (3).

Johnson (23) devised a triangular key whose equilateral slides measured 20 cm. The subject tapped successively at each of the corners.

The tapping board and the telegraph key have been used by the majority of experimenters. The following experiment was designed to get actual data on the relative value of the two tapping devices:

Sixteen observers, nine men, seven women. Tapping board and stylus, telegraph key; 1 mm. amplitude, 100 g. resistance, clamped to top of table. Ten trials taken with each individual, five on each apparatus. Eight observers were given the first five trials on tapping board and the other eight observers were given the first five trials on the key.

The results show an average faster rate of 1.3 taps in a five second period of tapping. Eleven subjects showed faster work on the key and five on the tapping board. Four of the later five, however belonged to the group of eight tappers whose five trials on the tapping board *followed* their five trials on the key. This brings in the effect of warming up. The second five trials were faster on the average by 1.7 taps during a five second period.

There are, however, some manifest objections to the tapping board device. The amplitude of the up and down movement can not be regulated: some observers will make large movements in spite of all charges to the contrary on the part of the experimenter. Whipple's (51) fear that to impose a restriction on the type of movement would reduce the record of many subjects seems unfounded. To make the movement uniform is just what is desired. A similar source of error is a scraping movement on the tapping board. A very slight tap, for example, when the stylus is allowed to bounce on the board, is not accurately recorded. The telegraph key on the other hand is not open to these objections. The telegraph key was therefore adopted as the tapping instrument. It has an additional adantage in being a staple article, purchasable anywhere.

The amplitude of the telegraph key. The amplitude as here considered is measured at the button of the key, the distance the observer must move the key to make a tap. Bryan (10) found that extent of amplitude made no difference in the number of taps accomplished. Binet and Courtier (5) suggest that the shorter the movement, the slower it is made; within limits, a series of fast movements are made in approximately equal time regardless of length of movement. Von Kries (45) considered a certain median distance of about 10 mm. the optimum amplitude. In Bryan's (10) figures no more than seven records were made for each amplitude. Binet and Courtier (5) offered no data in support of their statement.

The matter was therefore again put to experiment, as follows:

1mm., 3mm., 7mm. amplitudes. Amplitude measured at the button of the key. 100 g. resistance. Average time per tap given in hundredths of a second, computed for 25 taps. Hence, the smaller score, the faster rate. 18 observers, 6 trials taken double fatigue order. Result: average time— 1 mm., .128 sec.; 3mm., .130 sec.; 7mm., .134 sec.

Thus the 1 mm. amplitude results in slightly faster tapping than the 3mm. amplitude, and noticeably faster than the 7 mm. When asked to state which amplitude they liked best the observers were evenly divided between 1 mm. and 3 mm. preferences. It was evident in giving the test that the 7mm. distance was too long. It was very difficult to make observers go the full amplitude of 7 mm., they would try to shorten the distance of the tap. Without doubt it takes more time to move 7 mm. than 1 mm.

The same was true of 3 mm. but to less extent. It seemed that for an occasional person, a rapid movement of only 1 mm. in extent was too tiny for his motor set-up; i.e., for natural work. But this disadvantage was so slight and occurred so rarely, that it was not considered of sufficient importance to forsake the small amplitude. Because of the faster results obtained it was decided to adopt the 1 mm. amplitude.

The recording instrument. There are two general classes of recording methods: (1) the graphic record and (2) some form of counter, either electrical or mechanical. The following investigators recorded the tapping by the graphic method, usually the smoked drum: Whipple (51), Johnson (23), Woodworth (54), Smith (39), Dressler (14), Moore (32), Kohnky (27), Wells (47), Bingham (7), and Benedict, Miles, Roth and Smith (3). The following used some form of electric counter: Hollingworth (20), Davis (13), Pyle (34), Stecher (41), Link (29), Marsh (31, and Bagley (2). Some kind of mechanical counter was used by Bickersteth (4), Bolton (9), Thompson (43), Kelley (24), and Gilbert (18). Gilbert's (18) counter was an ingenious arrangement of an alarm clock.

The graphic method furnishes accurate detail. It is the only method by which the time of separate taps can be studied, and consequently is the sole means of measuring the regularity of the tapping throughout the tapping period.

In the early part of the present investigation, the graphic record with Seashore's duplicate recorder was used; the time line was marked off by a pendulum beating seconds. By this method the number of taps made in a given second could be ascertained but not the duration of a single tap. The method of the phonograph chronograph, as developed in the Iowa laboratory, proved a much more refined graphic procedure. The taps were graphically recorded on a revolving paper disc. By placing the disc on a large ruled dial scale, the duration of each tap would be read directly in thousandths of a second when the disc was accurately timed to revolve once per second. A good phonograph revolves to an error of .001 second per revolution.

The disadvantages of the graphic record, however, are as evident as its merits. The chief drawback is the laborious process of reading the records. This factor practically limits its usefulness to the laboratory.

To facilitate the recording, the counter method was investigated. The first tried was the Harvard tapping machine with its Veeder chronometer. This apparatus was neat and compact but it was discovered that it would not record accurately as high as ten taps per second for the following reasons: the armature of the magnet was poorly arranged, the magnetic pull being diagonal and of least force at the beginning of the armature's movement, where it should be direct and strongest; too long a movement of the armature was necessary to operate the rachet; and the chronometer counted on the break which made it susceptible to tremors. The Hollerith dial chronometer also proved to be unsatisfactory.

The timing instrument. Besides the selection of the recording device is the choice of an appropriate and accurate means of timing the tapping period. Moore (32), Seashore (37), and Johnson (23) used a 100 vd. fork in connection with the graphic record; this is, of course, the most accurate method and is of value when the purpose is to study the duration of a single tap, but it is manifestly too cumbersome when the duration of the tapping period is five seconds (and with many investigators the period is much longer). Whipple (51) used a seconds' pendulum, Dresslar (14) a clock for recording seconds, and Benedict, Miles, Roth and Smith (3) a Seth Thomas clock which divided the tapping into two second intervals. These methods are all dependent on a graphic recording instrument. Of the investigators who used counters, Wooley (56) and Woodworth (54) used the stop watch and Davis (13) an ordinary watch. Many experimenters made no mention of the means of measuring time.

It was decided to determine by experiment the relative accuracy of the ordinary timing methods. Five methods were tried: two auditory (metronome, and click in the receiver from the revolving disc of a timed phonograph) and three visual (swinging pendulum, the stop watch, and the ordinary watch). Three observers. Five trials on *each* method.

Auditory. Av. error in estimating a five second interval:				
Metronome	.055	sec.	M.V.	.026
Click in receiver	.116	"	" "	.030
Visual.				
Swinging pendulum	.179	"	" "	.104
Stop watch	.212	"	" "	.067
Ordinary watch	.317	"	" "	.156

The inaccuracies of timing with the stop watch and the ordinary watch are evident.

The new tapping apparatus. An attempt was made to construct a counter which would obviate the main difficulties in recording and timing which have been mentioned. In its final form the counter devised consisted of a Veeder chronometer mounted with a double coil door-bell magnet of eight ohms' resistance, size of each coil approximately 1 1-2 inches by 1 inch. The magnetic pull on the armature was direct and it was attached to the chronometer at a small radius, thus necessitating but a short movement of the armature to operate.[1]

The counter was further equipped with a double action key which, connecting with the metronome circuit, insured accurate timing of the tapping period. (See Fig. 1.)

Tests showed that it would record a 20 vd. fork, and no tapping reaches that speed. The voltage required is listed as follows:

Insufficient to operate	3.8 volts
Sufficient to operate a 10 vd. fork accurately	5.3 volts
Sufficient to operate a 20 vd. fork accurately	6.8 volts

The method of manipulation is as follows: The tapping is started when the contact is open in the metronome, at which time the bar (S K) is horizontally thrown to the contact at (M 2). The recording will then begin as soon as the circuit is closed in the mercury cup of the metronome. During the succeeding second, when the wire is in the mercury, the bar (S K) is pressed down to a contact at (S), thus the circuit is shunted from the metronome. The purpose of the shunt, is of course, to keep the

[1] This apparatus is now made by C. H. Stoelting Co., Chicago.

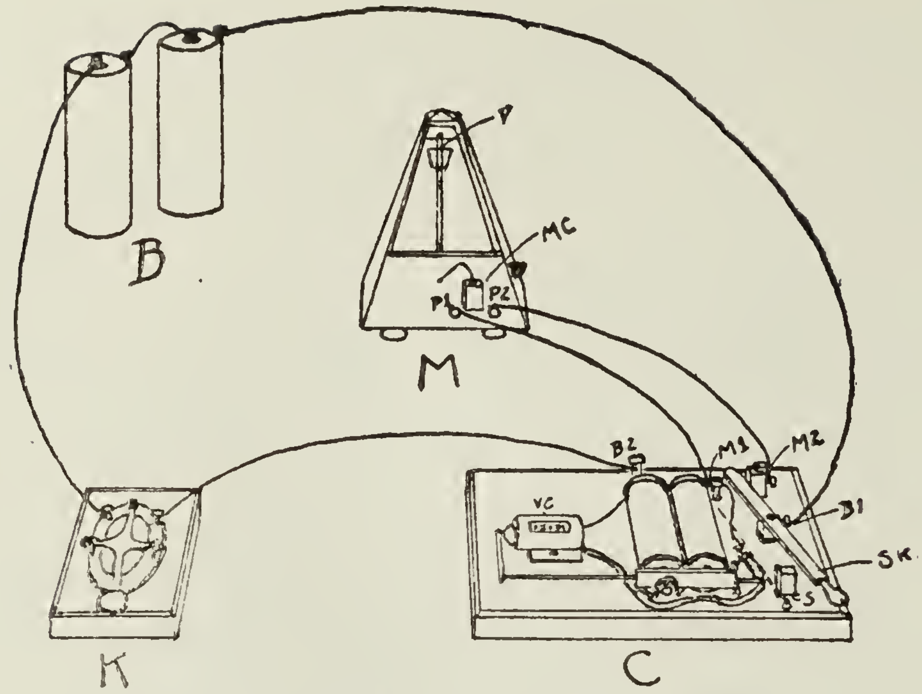

Fig. 1. The tapping apparatus.

M is a metronome with a mercury contact; B, a battery; K, a telegraph key; and C a counter. The Veeder counter VC is operated by the magnet. The key SK closes the circuit through the mercury contact by a horizontal movement. A downward pressure of this key makes contact at S and shunts the mercury contact.

circuit closed while the mercury contact is broken. On the fifth second, when the wire is again in the mercury, the key (S K) is raised; this permits the metronome contact to determine the end of the tapping period. Immediately after the breaking of the circuit in the metronome, the experimenter breaks the horizontal connection at (M2) and tells the subject to stop tapping.

Thus the experimenter's own reaction time is entirely eliminated. Any exact interval of time can be taken, with the single reservation, however, that the interval of time must be an odd number of seconds. The limit of accuracy is set by the accuracy of the metronome beat.

Methods of Procedure

Type of movement and positions in performance. Tapping tests have been made use of in various movements. Most of the arm joints have been subjected to experimentation; tapping has been done even by the foot and the big toe. The full arm shoulder joint was involved in one of Kelly's (24) experiments. Binet and Courtier (5) used the forearm movement and asserted that it was faster than either the finger or the full arm and also the most natural movement. Dresslar (14), Binet and Vaschide

(6), and Wooley (56) rested the forearm on a firm support and confined the tapping to the wrist as far as possible. Bolton (9), Moore (32), and Benedict, Miles, Roth, and Smith (3) used the finger movement only. To do so, it was required in most cases to strap the forearm and wrist to the table. Bryan (10) tested the speed of all the joints of the upper extremities and found the elbow and the wrist the fastest joints. His results are as follows:

	Taps per second
Shoulder	5.2
Elbow	8.8
Wrist	11.4
Metacarpo-phalangeal	7.6
First interphalangeal	6.0
Second interphalangeal	4.3

McAllister also found the elbow and wrist to be the fastest joints. Kelly (24) stated that tapping with forearm is faster than with the forefinger in about the ratio of 15 to 13.

With all this unanimity of opinion, it was not difficult from the point of view of maximum speed to adopt the forearm movement. The wrist was allowed free play in so far as it contributed to the forearm tapping movement; in short, the movement chosen was the easiest to perform, the most natural, and in addition the most rapid.

An extended comparison of horizontal and vertical tapping under various conditions revealed a very slight advantage in speed for the horizontal position when the horizontal key was located in a convenient position under the table, 70 cm. from the floor. However, the vertical tapping was adopted as the standard method of giving the test because: practically all former investigators have used this position; the key is more easily set up on the top of the desk or table; the vertical tapping has the psychological advantage of holding the attention better, and therefore getting better effort from many observers.

Arm position in tapping. Many experimenters rested the elbow and forearm on the table: of these Binet and Vaschide (6), Stecher (41), Davis (13), and Dresslar (14) are examples. Gilbert (17) on the other hand maintained that the arm held free from any support was the most rapid way of tapping. The two positions were subjected to experimentation as follows: (1) observer sitting alongside the table with arm resting on it; (2) observer facing table with arm held free from any support. The free arm position gave noticeably faster results—.120 sec.: .129 sec. Resting the arm on the table appeared to interfere with the tapping. With but one exception, all observers expressed a preference for the free arm position. The free arm position also showed greater regularity of tapping.

Finger positions in tapping. Bagley (2) made use of the rather novel method of "trilling" a Morse key. The objection to "trilling" as practiced by pianists is that ability in this line is a result of training. It would be quite difficult for some and easy for practiced pianists. Any such movement, which is essentially accessory rather than fundamental, would be unfair as a measure of motility.

A more common finger position has been that of holding the finger just free from contact with the key. A second finger arrangement was the holding-key position in which the key was grasped by the thumb and two fingers.

Experiment on twenty subjects revealed no significant difference in the speed for the two methods. (Key grasped, .127 sec.; key free, .129 sec.) The important defect of free-key tapping movement is that the amplitude of the movement can not be kept constant. Some observers insist on lifting the fingers from the key during the tapping, unless they in some way have hold of the key.

The length of the tapping period.—The literature on tapping shows a great assortment of methods in regard to the duration of the test. Bolton (9) chose 5 seconds, Davis (13) 8 seconds, of which only the last 5 seconds were recorded. Smith (39) used 8 seconds; Abelson (1), Kirkpatrick (26), and Benedict, Miles, Roth and Smith (3) 10 seconds; English (15) and Burt and Moore (11) 15 seconds; Wells (50) 20 seconds; Gilbert (17) 45 seconds; Kelly (24), Link (29) and Bickersteth (4) 60 seconds; Thompson (43) 2 minutes unless the subject had already given out; and Moore (32) continued the experiment until the subject could tap no longer. Some investigators record time instead of number of taps. Seashore (37) measured the duration of one complete movement of the finger (a tap) in hundredths of a second. The record was taken at the end of 7 seconds of tapping. Marsh (31) took the time for 100 taps, Dresslar (14) for 300, and Hollingworth (21) for 500 taps.

Doubtless the use to which the test is put will have an important bearing on the duration of the tapping period. If, as in the present investigation, the purpose is to measure rapidity of movement, it would be useless to continue the experiment after the speed had begun to decrease noticeably. Wells' (50) figures for 30 seconds of tapping showed a continuous decrease in speed, the first 5 seconds being fastest and the last 5 seconds slowest. Davis (13) noted in this connection that on lengthy series of taps there were waves of rapidity, followed in each case by slowing-up. The ease of rapid tapping varied.

The work of Benedict, Miles, Roth and Smith (3) is an example of the ten seconds' period. Their work is the latest thorough study of this problem. But a period of ten seconds is too long for a test of mere speed: this was clearly shown in the records of these investigators. Fatigue soon became operative, there being a steady fall in each of the five two-seconds' intervals throughout the ten seconds. The progressive decrease from each two-seconds' interval was uniformly 0.3 or 0.4 of a complete finger movement. Bolton (9) stated that even five seconds was too long for the most rapid work.

To study the tapping throughout the five seconds' interval it was necessary to revert to the graphic method of recording. The average number of taps in each second of the five-seconds' interval for 18 observers, 5 trials each, was: 1st second, 7.2; 2nd second, 7.4; 3rd second, 7.2; 4th second, 7.1; and 5th second, 7.1. Within an interval of 5 seconds the decrease in speed is very little.

Related to the duration of the tapping period, is the selection of the proper time to start the recording. Bingham (7) insisted that the very first taps should be recorded. In the present study it was decided to exclude the first few taps because a study of the graphic record showed frequent irregularities in the first part of the second of tapping, probably due to the inertia of getting started. Accordingly in the standardized procedure, the stimulus "Go" is given about a second before the recording begins.

The optimum number of trials. No investigator recorded more than five trials. Wells (50) and Bolton (9) each took five series, English (15) recorded four, which were preceded by a ten seconds' practice trial, Bagley (2) and Benedict, Miles, Roth and Smith (3) took three and Smith (39) only two trials. In the study of this question which follows it is quite clear that the observers do not reach their maximum speed in five trials. An initial warming up period seems to be necessary. Thirty observers, ten men and twenty women were given twenty-five trials of tapping, preceded in each case by at least two preliminary practice trials. The results of the thirty observers were averaged for each trial. With conditions standard, the following figures show average number of taps in five seconds for successive periods.

1st practice	2nd practice	1st	2nd	3rd	4th	5th	6th	7th	8th
36.6	38.3	38.8	38.9	39.4	39.5	39.5	39.9	39.5	40.4

9th	10th	11th	12th	13th	14th	. . . .	23rd	24th	25th
40.1	40.3	40.7	40.6	40.1	40.8		41.1	41.4	41.1

The results show that fatigue does not operate to any noticeable extent during twenty-five successive trials, when the tapping period of a single trial is no more than five seconds. After the fifteenth period there is essentially no further improvement and no falling off. The average performance for different number of trials in terms of taps per 5 sec. is as follows:

Average for 20 trials 40.3 m.v. .6
Average for 20 trials 40.3 m.v. .6
Average for 15 trials 39.9 m.v. .3
Average for 25 trials 40.4 m.v. .7

Obviously it would be desirable to give as few trials as possible, if in doing so, there would be no sacrifice of speed or accuracy. The scores computed from twenty-five trials, showed a correlation with scores, computed from twenty trials, of r. .99, P.E. .012 (Pearson's product-moment formula). Twenty trials, then, give just as reliable a score as twenty-five. Twenty trials may therefore be adopted as the standard method of procedure. Twenty trials would obviously be impracticable with a graphic recording method, but with a counter which is thoroughly reliable, they can be quickly and easily taken.

Directions for giving the test

To insure uniformity of procedure in the use of this as a standard test, the following directions to the experimenter have been formulated:

Start the metronome and say "Ready" when the wire enters the mercury cup and say "Go" when the contact is open, at the same time throwing the key to the left. The tapping will then begin while the circuit is broken in the metronome, but the record will not begin before the metronome circuit is closed, approximately half a second later. During the succeeding second, when the wire is in the mercury, press the key down, thus shunting the circuit from the metronome. On the fifth second, when the wire is again in the mercury, raise the key, thus breaking the shunt, and permit the metronome contact to determine the end of the period. During this break in the metronome circuit call "Stop" and throw the key to the right.

Seat the observer facing the key. Adjust the stool to his height so that the forearm is in a horizontal position. The hand not in use should grasp the table. Direct him to plant both feet firmly on the floor and lean slightly forward with the entire body in an alert and tense position, ready for action. Drill the observer on the importance of being in the same attitude as in starting for a race—a race of five seconds.

Then engage in preliminary practice so that the observer may become familiar with the working of the key. Demonstrate the thumb and finger method of holding the key. Correct any wrong procedure, such as excessive arm movements, or attempts at trembling. This practice tapping should serve also as a warming up process in which the observer gets set for the heat. The amount of this corrective preliminary work should vary with the need of the individual. One individual may be nervous and needs to be quieted down. Another may be lethargic and needs to be spurred. Emphasize speed only; not regularity. Do not start the recording until you are assured that the best form and the best effort are secured for speed. If insuperable difficulties appear in this preliminary practice, make full and detailed note of these for the interpretation of the record.

At the end of each trial announce the result, and challenge the observer to excel his record. Remind him of the importance of focusing all his effort into the short period of five seconds. Allow a few moments between trials and see that the observer relaxes completely. If there occur noticeable breaks in the tapping of more than twice the duration of a single tap, throw out that record before reading what the record is, and give him another trial. Record results for twenty trials.

To help get the maximum effort from the observer the object of the test is briefly explained; then the "Charge" is given, and finally praise of his efforts and a word of encouragement after each trial.

Just before the preliminary trials and again before the first recorded trial, give this charge: "Remember it is speed that counts. Let nothing interrupt you until I call 'Stop.' Keep your eyes on the key. Do your utmost. Tap as fast as you possibly can."

If the charge does not seem to be effective, use any device to stimulate the observer or quiet him, as the case may demand. The test is made under the supposition that the experimenter has been successful in securing the observer's very best effort.

Sources of error in tapping. A sudden muscular rigidity in the arm, a sort of momentary paralysis in which the arm moves neither up nor down, occasionally interrupts the tapping. These "breaks" can often be avoided by having the observer tap less forcefully and with a less tense position of the arm. It is not uncommon to have attempts at increased speed result in merely increased force. Too much muscular effort in tapping interferes with the subject's maximum speed.

Smith (39) called attention to "tremor" and considered its rate as different from the rapidity of voluntary movement. The observer should be shown that distinct up and down movements of the forearm are necessary.

The following movements call other joints into play and slow down the rate: shoulder joint movement of the full arm, a finger movement, a hand and wrist movement of large amplitude while the fingers still hold the key, and side movements of the hand. They are all examples of wrong procedure which must be corrected.

Lifting the hand high from the key between taps is but another example of wrong procedure. Another is the attempt to alternate the tapping between the pointer and middle fingers, as in the trilling movement on the piano, which interferes.

More central, subjective factors sometimes lessen the reliability of the results: unfamiliarity with key, a hesistancy in bending all effort to show a maximum speed, a failure to assume an alert, tense position of the body; wandering of attention (most noticeable in children) from the tapping to the clicking electrical counter; and the tendency of those experienced in telegraphy to want to send symbols, etc. Proper cautioning and tact are usually effective in overcoming these difficulties.

The effect of practice on the tapping rate. Practice in tapping resulted in increased regularity of performance rather than in increased speed according to Johnson (23) and Raif (35). Dresslar (14) thought that practice had no effect after the third day but Wells (48) stated that the practice curve was very gradual in ascent and fluctuated somewhat from day to day. Johnson (23), after experimenting with the toe tap, asserted that the effect of practice is greater in proportion to the undeveloped state of the muscles. Davis (13) concluded that the results of practice were central rather than peripheral, the central factors being a development of motor centers and an increased will power and concentration of attention during the tapping period.

To determine the effect of practice on ability in this test, six normal adults were chosen to repeat the test daily, under uniform conditions for a period of twenty days.

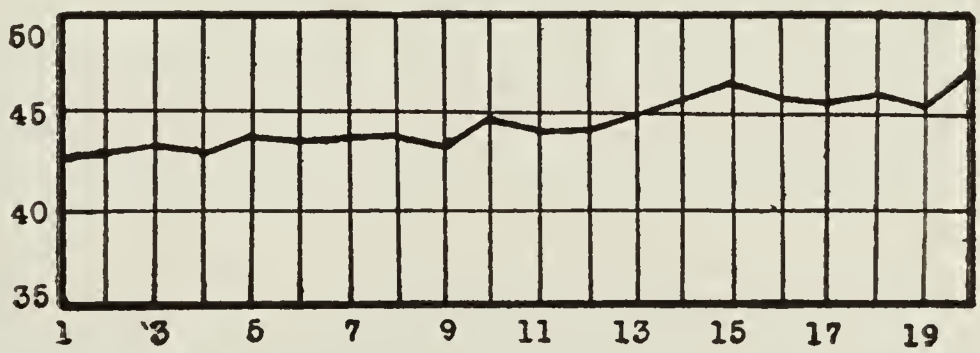

FIG. 2. Twenty day practice experiment, six subjects: numbers at bottom, successive days; numbers at left, average number of taps in five seconds.

The results of this practice series are shown in Figure 2. The mean variation is so constant for all observers that there is no object in representing it in the graph. The amount of gain by practice is very small. The curve is quite different from the learning curve in a more complex process. Three observers showed improvement, three did not; where gain was found, it was due to improved technique, less perversion of procedure in attempted trembling, etc. Where improvement did not occur, the observers developed good technique the first day, were quite regular in their performance and put forth their maximum effort.

The experiment bears out the statement of Binet and Courtier (5) to the effect that low variability is a sign that the effect of practice has already been accomplished, and there is no chance for much further improvement. Of two persons having the same average score, the one with the high variability has better chance for improvement.

Aside from the question of improvement, other items relevant to rapidity of performance were noted. Mental work immediately preceding the test resulted in increased speed, as mentioned by Dresslar (14). Nervous irritation resulted in faster work; likewise irritability due to a cold. Sitting in a cold room caused a slowing up or a longer preliminary practice period to reach normal performance. More than the usual amount of sleep resulted in muscular and nervous lethargy and a retardation.

The effect of practice is very important in considering just what the test measures. If the ability required in the test is fundamental rather than accessory, learning will play a very small part and there will be very little improvement with practice. And this is seemingly just what the practice experiment showed. No improvement would indicate that a *basic* motor capacity is being tested.

Rates and norms. The average rate is of course conditioned in large part by the duration of the tapping and the methods of procedure. When speed of performance is the one object in view, the average rates have been recorded as follows: Dresslar (14), 8.5 taps per second; Franz (16), 8 per second, Wells (48) found an average of 35.3 taps for the first five seconds of his thirty seconds' interval. Woodworth (54) placed the upper limit at 10-11 taps per second; Bryan (10), 11 per second for a short interval; and Von Kries (45), 10-11 per second but designated 11-12.4 per second as the maximum rate of innervation. Wells (48) found that the fastest and slowest subjects varied in the ratio of about 3.2.

Wells (48) noted that the m.v. was usually 1% to 3% of the rate and Bryan (10) stated that the m.v. was rarely more than one tap per second. Fatigue as a factor in variability began to show after ten or fifteen seconds' work, according to Bryan (10). As to regularity, Bliss (8) found that the time interval between taps was constantly varying, it was seldom exactly the same for two successive taps. This time variation within the series was quite evident in the present study's experimentation on

University sophomores. The time of day was accompanied by variations in rapidity; that afternoon tapping surpasses that of the morning was noted by Dresslar (14), Hollingworth (21), Marsh (31), and Stecher (41). Dresslar (14) placed the maximum at 4 p. m. but according to Gilbert (17) the later periods of the evening were the most rapid of all.

In the autumn of 1917 164 sophomores were tested. Three five-second trials for each individual were graphically recorded. The figures shows median time per tap (sec.) .116, m.v. .012; mean .119, m.v., .012. The distribution is given in Table I on the basis of which percentile norms are given in Table II.

TABLE I. *Distribution of tapping time*

Scale in hundredths of a second per tap	Men No.	%	Women No.	%	Total No.	%
8.0- 8.4	1	.9	0	.0	1	.6
8.5- 8.9	2	1.8	0	.0	2	1.2
9.0- 9.4	2	1.8	0	.0	2	1.2
9.5- 9.9	5	4.7	0	.0	5	3.0
10.0-10.4	13	12.2	3	5.1	16	9.7
10.5-10.9	14	13.2	6	10.3	20	12.2
11.0-11.4	18	16.9	9	15.4	27	16.4
11.5-11.9	21	19.8	3	5.1	24	14.6
12.0-12.4	14	13.2	9	15.4	23	14.0
12.5-12.9	6	5.6	5	8.6	11	6.7
13.0-13.4	2	1.8	5	8.6	7	4.2
13.5-13.9	3	2.8	4	6.9	7	4.2
14.0-14.4	2	1.8	4	6.9	6	3.6
14.5-14.9	2	1.8	4	6.9	6	3.6
15.0-15.4	0	.0	2	3.4	2	1.2
15.5-15.9	0	.0	1	1.7	1	.6
16.0-16.4	0	.0	2	3.4	2	1.2
17.0	0	.0	1	1.7	1	.6
23.0	1	.9	0	.0	1	.6
Totals	106	99.2	58	99.4	164	99.4

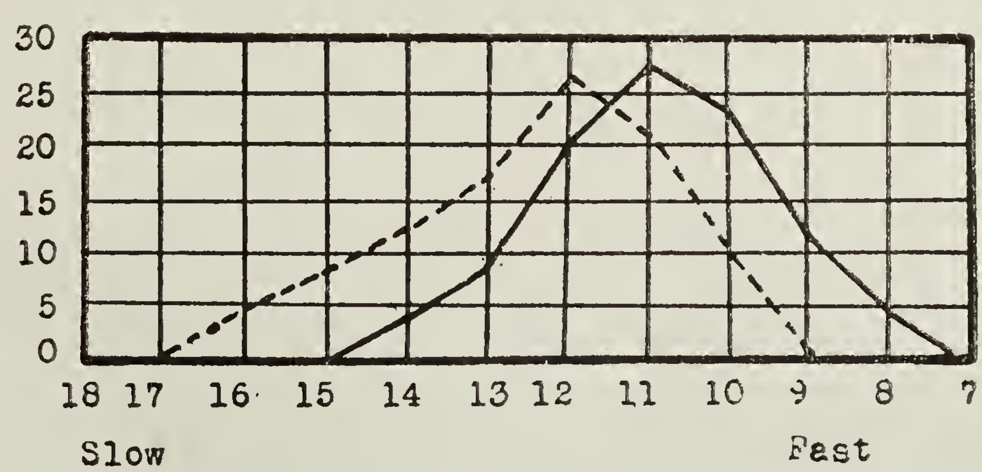

FIG. 3. Speed in tapping: dotted line, women; solid line, men: numbers at bottom, scale in hundredths of a second per tap; numbers at left, per cent of cases.

TABLE II. *Percentile ranks for adults*

(Derived from 164 cases, sophomores in State University of Iowa)

% Rank	Time per tap	Taps per sec.	Taps in 5 sec.
100	.083	12.0	60.0
95	.097	10.3	51.5
90	.102	9.8	49.0
85	.104	9.6	48.0
80	.106	9.4	47.0
75	.108	9.3	46.5
70	.111	9.0	45.0
65	.112	8.9	44.5
60	.113	8.8	44.0
55	.114	8.7	43.5
50	.116	8.6	43.0
45	.118	8.4	42.0
40	.120	8.3	41.5
35	.121	8.2	41.0
30	.124	8.0	40.0
25	.126	7.9	39.5
20	.130	7.6	38.0
15	.137	7.29	36.5
10	.143	6.99	35.0
5	.148	6.7	32.5
1	.238	4.2	21.0

Age and sex differences.

The tapping rate increases steadily between the ages of 6 and 19. This fact was noted by Gilbert (18), Bolton (9), Bryan (10), Smedley (38), and Bickersteth (4). Each writer, however, offered certain limitations. Bolton (9) stated that age differences of 8 and 9 year old children were less than individual differences of those ages; also that increase of motor power was less marked with mentally inferior children. Bryan (10) estimated that the rate of the child of 6 was two thirds the rate of the youth of 16. According to Gilbert (18) and Smedley (38), the increase of speed with age had one marked exception, at ages 13 to 14 there occurred a slight but noticeable falling off. Gilbert (18) attributed this to puberty. Bickersteth (4) noticed a slight falling off at age 15. Gilbert's (18) table of norms for ages 6 to 19 is typical of experimentation of this kind and is reproduced for purpose of comparison with results of the present study, in which the children of the University Elementary School were tested. About one hundred and thirty children of Grades I to VI inclusive were given the tapping test under standard conditions.

TABLE III. *Age and Sex Norms*

	GIRLS				BOYS			
	Gilbert		Ream		Gilbert		Ream	
Age	Taps	M.V.	Taps	M.V.	Taps	M.V.	Taps	M.V.
5			16.6	1.2			18.8	1.1
6	22.3	2.2	20.3	1.3	22.1	2.1	20.8	1.0
7	24.5	2.7	22.7	.7	23.3	2.7	22.7	1.2
8	26.0	2.5	25.0	.7	25.0	2.4	27.1	.8
9	26.7	2.5	28.0	.9	27.1	2.4	28.2	.8
10	26.2	3.6	28.7	1.0	28.3	2.6	31.1	1.2
11	28.0	3.1			28.1	2.2		
12	29.3	2.2			30.1	2.9		
13	29.5	2.7			31.1	3.8		
14	29.4	2.6			32.4	2.9		
15	31.3	2.7			34.0	2.6		
16	32.2	3.1			34.0	3.1		
17	33.8	3.0			34.4	2.2		
18	34.3	2.4			36.0	3.1		
19	35.3	3.1			36.7	3.3		

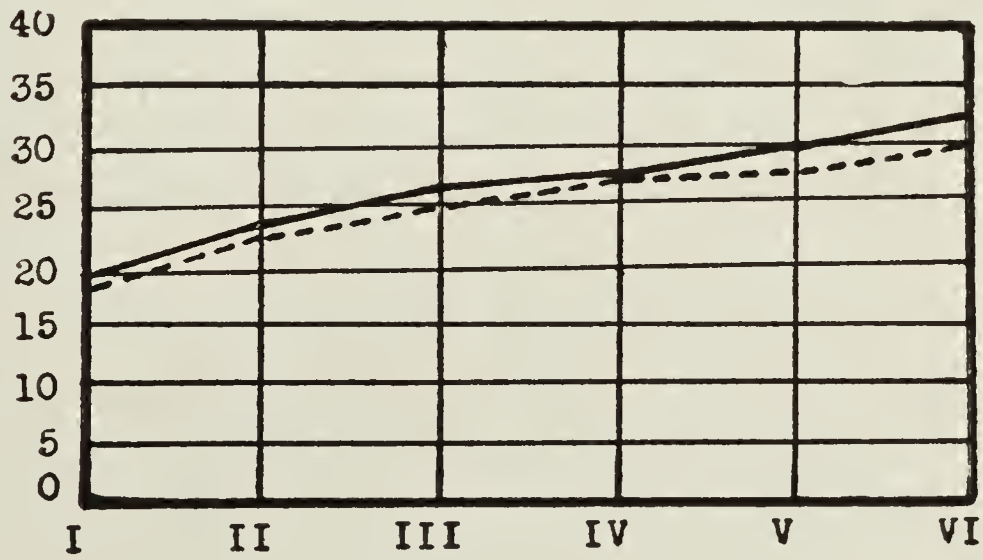

FIG. 4. Variation in tapping with grade: solid line, boys; dotted line, girls: Roman numerals, school grade; Arabic numerals, numbers of taps in 5 seconds (Ream, Table III).

A very clear verification is found in these records of the increase in tapping rate with age and physical growth. With the exception of ages 6 and 7 the rates are noticeably faster than Gilbert's (18), and on the whole, the mean variations are much smaller.

As regards sex differences investigators are practically unanimous in the conclusion that men are faster than women and that boys excel girls. Cattell (12), Thompson (43), Smedley (38), Bryan (10), and Bagley (2) are examples. Bolton (9) found that girls surpass boys at the ages of 8 and 9, Gilbert (18) from age 6 to age 8 inclusive, and Bryan (10) noted that girls excelled at age 13, but were inferior in all other cases.

Burt and Moore's (11) records showed that 68.8% of the boys exceeded the median score of the girls; Thompson (43) found 88% of men faster than the median for women; and with Hollingworth and Poffenberger (22), the tapping test ranked highest, 71%, in number of men reaching and exceeding the median performance of women. These findings were corroborated in the present investigation on adults. Sex and age differences are shown graphically in Fig. 4, and Fig. 5.

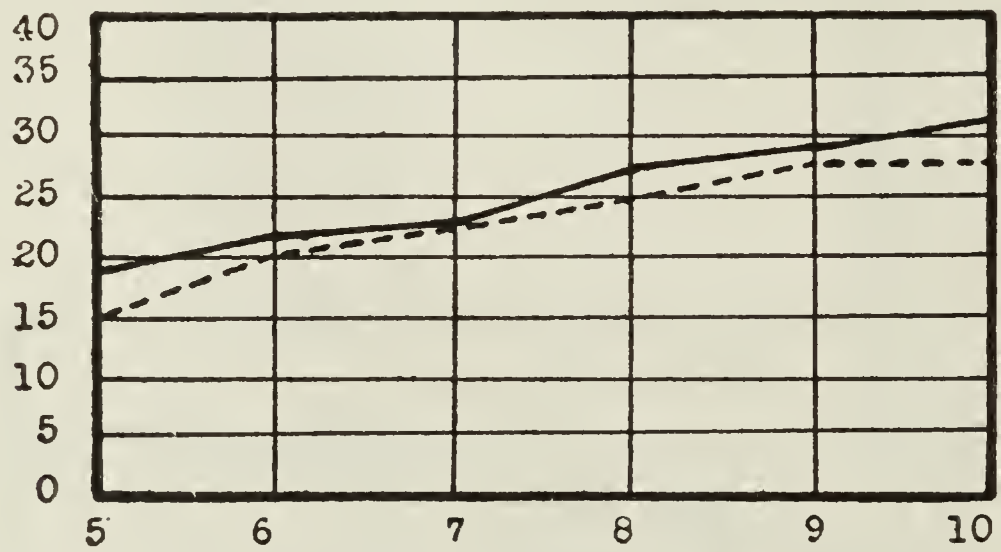

FIG. 5. Same data as in Fig. 4, expressed for age instead of grade.

Wells (49) considered women less variable than men when he prolonged the tapping test into a fatigue test but this conclusion was not borne out in the present study. The women showed larger mean variations on every trial than the men. However, the initial large variation of the women was materially reduced on later trials. A number of the women seemed to show an initial hesitancy in beginning a test of motor ability.

Relevant correlations.

A great many investigators have been anxious to determine the relationship between motor and mental capacities. The tapping test, as one of the simplest motor tests, has been frequently correlated with mental tests. Results and conclusions are far from unanimous. The correlation with mental ability was found to be positive by Bolton (9), Smedley (38) and Kirkpatrick (26). Binet and Vaschide (6) reported it positive with children of 12 years and negative between the ages of 16 and 20. Gilbert (18) found bright children generally better in tapping. Dresslar (14) reached the conclusion that the rate of voluntary movements was something of an index to central nervous activity. Burt (11) reported correlations with intelligence of .44 at one school and .28 at another school. Abelson (1) having tested 188 girls found marked correlations with interpretation of pictures, crossing out rings, memory for names of objects, and memory for commissions. Stecher (41) reported interesting correlations with mental multiplication r, .24; with aiming r, .31; with hand steadiness r, .07; with arm steadiness r, .03; and with eyelid tremor r, .21.

Other writers, however, were just as insistent that performance in tapping bore no relation whatever to mental brightness. Among these were English (15), Gilbert (18), and Smith (39). Three out of four highest scores, recorded by Smith were made by demented epileptics. Bagley (2) and Bickersteth (4) even maintained that the relation was inverse between mental and motor ability. From the evidence at hand, an assertion of positive relation between the two types of performance is certainly unwarranted; what is evident, however, is the need for more careful investigation along this line. Burt (11) made an interpretation as follows: "So far as motor rapidity is the function of temporary 'facilitation' of the paths of neural discharge, it appears also to be a function of intelligence; while so far as it is a function of permanent 'canalization' of those paths, it is but slightly or inversely related to intelligence."

Much more interesting is the question of a relation between tapping rate and proficiency in certain occupations. Link (29) tested employees of the Winchester Arms Company. In the case of shell inspectors, tapping had the smallest correlation of any of his seven tests, r, .135, P.E. .071. In this kind of work, keen eyesight was the first essential. But in the case of gaugers, tapping had the highest correlation, r, .516, P.E. .071. In this work speed of movement was most important. Hollingworth and Poffenberger (22) found a correlation of .34 between tapping rate and proficiency in hand sewing. As regards piano playing, Raif (35) maintained that a high tapping rate was not necessary in order to become an artist in piano; for, he said, the fingers alternate in their movements, and it is never necessary to repeat any movement more times per second than the normal rate in tapping. However it can be contended that tapping as one measure of an individual's total motor set and equipment, may have a bearing on performance in music.

In the efficiency studies, Benedict, Miles, Roth and Smith (3) reported a decrease in rate with restricted diet and Hollingsworth (20) a decrease with alcoholic beverages, but the same writer reported that the use of caffein had a stimulating effect in the tapping test.

The correlation between speed score and regularity score, (M.V., 164 cases) proved to be r, .32, P.E. .05, showing that a positive correlation is present, but it is not marked. The four combinations of speed and regularity were found: fast and regular, fast and irregular, slow and regular, and slow and irregular. For the most part, however, the fast tappers were more likely to be regular and the slow tappers irregular.

The correlation between speed in tapping and simple reaction time (157 cases) was r, .21 P.E. .05. There was a positive correlation present but quite small, barely four times the probable error.

Factors conditioning rapidity of performance in tapping.

A number of writers have suggested that individual differences in rate are conditioned in a general way by fundamental neural factors. Wells (48) stated that physiologically the maximum rate is limited by the refractory phase of the synapses in the motor pathways. In consideration of motor development Bolton (9) similarly explained that it is based upon growth of interrelation between nerve elements. Arrest of growth is due to suspension in growth of associative connections. Von Kries (45) and Kirkpatrick (25) supported the view concerning the neural character of the limit placed upon the maximum rate. In addition to this important factor, Whipple (51) appended another condition, viz., the ability to coördinate voluntary movement. Evidently a certain amount of simple coördination is required in tapping. This second factor might help to explain Wells' (48) statement that although nervous temperaments were usually fast, some are below the average rate. He also stated that a fast rate is not always related to general quickness. Obviously general motor quickness is dependent also on power of coördination, temperament, muscular habits, training and environment. But the striking individual differences in performance can not be wholly explained by these contributing factors. Every individual has his own motor set-up, one is geared slow and another is geared fast. The chief factor in the different tapping rates which result is probably a physiological openness of nerve paths which is inherited. It enables an individual to maintain his approximate percentile standing in motility among individuals of his own age and development if the contributing factors mentioned above are constant.

To what extent ability in tapping is an inherited capacity no writer has stated. The extended practice experiment of the present study seemed to indicate that the test measures fundamental, basic abilities since improvement was on the whole, conspicuously lacking. The inference is that the motive neural set, undoubtedly an important condition of such basic ability, is inherited. There are other conditions, however, which are surely subject to training. Coördination of movement, regularity and smoothness of performance, illustrated by training in piano, are mentioned by Binet and Courtier (5) as improved by practice. Raif (35) likewise, emphasized the improvability of coördination of movement. Davis (13) noted that such results of practice as appeared, were central rather than peripheral, viz., (1) those dependent on the development of motor centers, that is, their improvement through exercise; and (2) those dependent on the development of psychical factors, attention and will power.

Subjective factors conditioning rate and regularity of performance.

Johnson (23) enumerated several subjective factors which affected individual differences in rate: physical condition, rapidity of heart beat, and body temperature, power of fixation of attention, and influence of emulation. Wells (48) noted increases with improvement of physical condition. However, on numerous occasions in the present study, the subject's estimate of his physical condition was no indication at all of the character or rate of his performance. Davis (13) also belittled the influence of general physical tone. But on the other hand, mental factors, as interest, effort, nervousness, or irritability resulted in increased rate. Stecher (41) said that tapping was peculiarly subject to an end spurt because of interest, rivalry, etc. Marsh (31) said in this connection: "Rapidity of tapping as it requires a minimum of control but a maximum of neural excitement, may be expressive largely of nervousness." The late evening produced the fastest scores; increased nervousness at that time of day was suggested as an explanation. The experimentation of the present study has led to the conclusion that the one subjective factor of real significance is maximum effort. Interest, rivalry, nervousness are mere accompaniments or expressions of the subject's desire to do his utmost. For this reason, the standard directions for giving the test, after the technique has been properly established, put all stress on stimulating the subject to his best effort.

To recapitulate, motor power is not a simple phenomenon but a complex of rapidity of control, steadiness and precision of movement, strength, endurance, etc. Motility is but one element of motor power, yet it is one of the most fundamental. It is stated by Bolton (9) that the muscles of the body form a graduated series, from the most fundamental to the most accessory. And all experimentation thus far points to the conclusion that the muscles' neural equipment used in the motility test are among those earliest developed and most fundamental in character.

Application and future experimentation.

In spite of all the experimentation to which the tapping test has been subjected, its use as a measure of motility has only begun. The present study has gone scarcely further than the standardization of apparatus and method of giving the test. There remains to be studied its diagnostic value in determining proficiency in many lines of industrial work. This can be done only by testing persons engaged or about to engage in the specific line of industrial work.

The tapping test may very possibly be of value in all those occupations and activities in which rapidity of movement is an important factor. Telegraphy, typewriting, hand sewing, music, sorting, folding, and packing work in factories are but illustrations of the vast array of human endeavors in which motility counts. Motility, as a basic motor capacity, will likely become one feature of a motor psycho-graph, in which an individual's motor abilities and weaknesses are graphically represented.

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SERIAL ACTION AS A BASIC MEASURE OF MOTOR CAPACITY

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An historical resumé of serial action and related experiments; conditions affecting the time and character of serial action measurements; apparatus and method; the effects of practice upon performance in the test of serial action; distribution of the groups tested according to speed and accuracy; the distribution of errors in relation to the sequence of stimuli; the relation of serial action to other measures used; the relation of serial action to other motor tests; application to vocational guidance and selection; conclusions; bibliography.

During recent years, tests and experiments involving continuous reactions after discrimination and choice, or "serial action," have been making their appearance in various garbs and for varying purposes. These developments have uniformly testified to an effort on the part of the psychologist to reproduce, in dealing with his laboratory problem, the actual conditions of ordinary daily motor activities more closely than occurs in the traditional forms of reaction time experimentation.

These newer measures of motor activities recognize the essentially fluid character of stimuli and reactions—their flux and flow within mutually interdependent continuous series. The stimulus constantly changes its nature and appeal, as the reaction process occurs; and the reactions, in turn, are always being adjusted to meet new conditions appearing in the stimuli.

Continuous discriminative reactions thus have their counterparts even in the early motor performances of the child, and they play an essential rôle in such simple acts as walking, manipulating objects, writing, and in fact, most of the responses of the individual to the world of things. They can be regarded as simple and basic indices of motor capacity, describing the motor efficiency of an individual with faithfulness limited only by the imperfect degree of standardization conditioning the measure. In the diagnosis, therefore, of motor weaknesses or incompetence, the performance of a subject in serial action may serve as evidence of his ability to deal in a formal fashion with common situations demanding motor adjustments.

Furthermore, proficiency in serial action is a basic factor in the development of skill in many vocational and avocational pursuits, such as those of the musician, the stenographer, the telegrapher, or certain factory inspectors. All organized series of activities in which there occurs a continuous interplay of successive stimuli and corresponding reactions involve this type of motor capacity. And success in these complex achievements will be conditioned fundamentally by the underlying ability of the individual in this sensorimotor performance.

It is possible, therefore, that the psychologist can so strip the reaction process of its secondary features, and so control its variables, both subjective and objective, that he can secure, by means of a test of serial action, a useful index of motor capacity. For he can postulate that the individual showing superior ability in this measurement, will, provided other factors do not interpose, achieve success in these various complicated attainments; while the subject of poor achievement in this test will probably be disqualified for attaining success in those same activities.

The purpose of the present investigation, therefore, is, first, to secure a simple and practical device for measuring speed and accuracy in serial action; second, to standardize thoroughly the variables in the procedure, thus leading to the gathering of reliable data; and, third, to measure the performance, in this test, of certain representative groups of persons. We may then be in a position to judge whether a test of this character possesses any utility for meeting certain problems of a clinical, vocational or industrial nature, wherein such sensorimotor capacities are involved.

For the apparatus used in the following tests, a simple commutator, serviceable in conjunction with many kinds of visual and auditory stimuli, has been attached to an ordinary typewriter, the keys of which were manipulated by the subject. In the procedure, as many of the numerous variables as possible were eliminated or at least considered, with an eye, however, constantly to practicability more than to laboratory infallibility. Four groups of subjects have been tested with this device: first, a group of 152 university sophomores who at the same time were taking seven other tests of motor capacities; second, 173 members of the Army Vocational School, who were beginning the army training for radio-telegraphers; third, 90 students in the schools of music at Northwestern and Iowa Universities; and fourth, 237 students in stenographic and commercial courses in Des Moines and Cedar Falls, Iowa. An effort is made, in each case, to discover the closeness of relationship between performance in the test and achievement in the vocational pursuits involved, by means of practical criteria.

An Historical Resumé of Serial Action and Related Experiments

The first experiments to measure the speed and accuracy of serial action were the card-sorting tests used by Bergstrom in 1893 and by Jastrow in 1897. The former (8, p. 356) introduced two methods of sorting a pack of cards into three piles, for the purpose of studying interference in practice. The latter (40) recognized in card-sorting a test of wide applicability. He devised a box containing eight compartments, in two rows of four each. A small set of twenty-four cards, or a larger of forty-eight cards, designed, sized and marked to facilitate speedy manipulation, was used for distribution into the correspondingly designated boxes. The symbols used for the classification consisted variously of eight numbers, letters of the alphabet, geometrical forms, and other designs. The subject held the cards, backs up, in his left hand, and distributed them while the experimenter gauged the time for the total performance with a stop watch. This type of test, with numerous variations in details, has been used by many later investigators, such as Bagley (4 and 5), Culler (22), Woolley and Fischer (82), Thompson (69), Whitley (76), Henmon (34), Link (46 and 47), Burt and Moore (14), Calfee (15), Cornell (21), English (28), Woodrow (79), and Weidensall (72). This form of serial action test has thus been extensively employed for many experimental, clinical and industrial purposes.

Laboratory apparatus for the automatic production of stimuli in series and the recording of serial reactions first appeared in the "psychergograph" devised in 1902 by Seashore (62), for "measuring mental work." This device consisted of a disc which revolved a distance of one one-hundredth of its circumference whenever any one of four reaction keys was struck, thus exposing singly through a small aperture in the screen above the disc, a series of one hundred visual symbols. Four kinds of stimuli, distributed in chance order, made up these symbols; and four fingers (the index and middle fingers of each hand) were associated with the respective stimuli. A multiple recorder for registering the time and the character of each reaction was attached. Seashore's aim was "to devise means by which it shall be possible (1) to call forth a relatively simple and definite complex of mental activity; (2) to repeat the same for any desired length of time without interruption; and (3) to measure (a) the amount of work done, (b) the time taken, (c) the quality of the work, and (d) fluctuations in speed." The subject faced the following simple problem: "Given, one of four known signals, to recognize it and make the corresponding one of four simple responses." Following this method, Florence E. Brown in 1904 made some experiments on "mental fatigue," to which reference will be made below.

In 1907, Coover and Angell (20) investigated the effects of practice in one type of serial action—Jastrow's card-sorting—upon efficiency in a related form of the test, arranged as follows. Attached to the carriage of a Blickensderfer typewriter was a strip of paper on which had been typewritten a series of the four letters, a, t, e, and n, in chance arrangement. Over the typewriter was fitted a screen, with an aperture of such diameter as to permit only one letter of the series to be seen at a time. Since the spacing of the letters in the series was the same as that of the typewriter action, the strip on the carriage could be so adjusted that for each stroke of a key, a new letter appeared in the aperture. The subject simply placed the index and middle fingers of both hands on the keys marked respectively a, t, e, and n, and responded to the successive stimuli by striking the corresponding keys. The time of reaction to each letter was recorded in another room by means of a kymograph.

McComas (49) in 1917 experimented with serial responses to differently colored lights, obtaining 10-minute records from a number of subjects. Through a small window in a screen were visible four differently colored electric lights, which were illuminated successively, and in chance order, by means of an automatic switchboard. The subject manipulated four telegraph sending keys, which were so wired that each of the four reaction movements broke the circuit by which one of the bulbs was illuminated, and at the same time made a circuit which actuated a marker on the kymograph. Having learned the proper associations between the lights and their corresponding reaction keys, the subject proceeded to extinguish the successive lights as rapidly as possible by pressing the respective keys. A series of sixty stimuli, each following upon the heels of the preceding reaction, was thus presented before the order of their appearance had to be repeated.

The serial action experiments of these investigators, although varying widely in purpose, method, exactness, character and complexity of stimulus and response, and other factors, all belong to the "B" type of reaction (Donders), in which the stimulus must be discriminated and the movement selected accordingly. Continuous reactions by the Donders "C" method, involving the discrimination of the stimulus and choice between movement and no movement, have also been the subject-matter of experiments. Dockeray (26) in 1915 measured "mental efficiency" over periods of sixteen minutes each, by means of four telegraph sounders, operated respectively by four keys under the control of the experimenter. The subject sat at a table with his hand on a reaction key. The experimenter, in beginning the test, operated one of the sounders several times in rapid succession, as a signal, to designate the particular sounder to which the subject was to react. The four sounders then followed each other, in chance succession, one second apart, for a period of one minute. The subject, discriminating the successive sounds, pressed the reaction key only in response to the sounder which had been designated. At the end of one minute, the experimenter signalled with a different sounder, to which the reactions of the following minute were to be made. The omissions and errors in reacting, and not the reaction times, were recorded. The purpose of Dockeray in these tests was to gauge mental efficiency before and after a period of physical work.

While these experiments compose a unique group of investigations, all involving the successive presentation of stimuli, one after another, each of which is disposed of, as it were, by a characteristic mode of reaction, there is a considerable number of other tests sharing with them certain general processes. Classifying them generally under such heads as tests of "association," "perception and attention," "discrimination," or "learning ability," psychologists have introduced many "cancellation," "code,", "substitution" and "motor coördination" tests, which should here be briefly considered.

The "substitution" test, particularly in that form known as the digit-symbol (or symbol-digit) test, has been used repeatedly for studies of "the speed of formation of new associations." The stimuli for which the associated elements or designs are to be substituted have consisted variously of: 20 letters of the alphabet associated each with one of the other letters (Lough, 48, Kirkpatrick, 42); the 26 letters associated with numbers (Jastrow; Starch, 66; Dearborn, 24); symbols, including the star, circle, square, cross, and triangle, each enclosing a digit for association (Woodworth and Wells, 81); nine such kinds of symbols similarly associated with digits (Dearborn, 24; Healy and Fernald, 33; Whipple, 74, I pp. 496-515; Pyle, 60; Pintner and Paterson, 57; Pintner, 56; Pintner and Toops, 58; Woolley and Fischer, 82; Army "Beta" and "Performance" tests); words to be coded into groups of short, horizontal lines, in accordance with a scheme applied to the alphabet (Gray, 32; Baldwin, 6); the dissected Maltese cross with the number 1, 2, 3 and 4 placed in the sections (Squire, 65; Carpenter, 16); three kinds of geometric forms given in two different colors, associated with the the first six digits (Squire, 65; Carpenter, 16); five kinds of geometric forms, exposed for 10 seconds, together with five digits (Anderson and Hilliard, 2); and pairs of multiplied numbers to be associated with their respective products (Thorndike, 70). In all of these "substitution" tests, the stimuli are presented *en masse* in company with their associated designs; but three diverse methods have been followed with respect to the length of time during which the key or standard is exposed. Whipple, Woolley and Fischer, and Healy and Fernald permit the subject to refer repeatedly to the key during the forepart of the performance, and at the end determine how well the associations have been stamped in, by removing the key. Gray, Squire, and Anderson and Hilliard expose the key for only a certain brief period, and upon its removal, the subject proceeds to make his responses from memory, by logical analysis, or by whatever means of recall he finds serviceable. Most of the other investigators permit the subject to utilize the key throughout the test. The first of these methods occupies a middle ground, with respect to difficulty, between the second and third, which are respectively the most complex and the simplest.

But even in its simplest form, the "substitution" test exceeds in complexity the serial action experiment. The stimuli are generally more elaborate, the associations more numerous and artificial, and the responses include the reproduction of designs instead of the simple stroke of a key. As a result, the time per reaction is greater, the "learning curve" is steeper, individual differences appear more extensively, and the variability in records is wider.

When the process of "substitution" is directed by reference to organized memory images or to conceptual processes, rather than by attention to a discrete series, either present to sense or recalled in terms of simple imagery, the test becomes analogous to the "Civil War" code test, used by Goddard (31), Terman (68), Healy and Fernald (33) and Chassell (19) in their classified mental tests.

In the less complex form of "code" test, the subject is given a very simple design, with only a small number of associations, as in the MacMillan "cross-line" tests, used by Healy and Fernald (33), and by Brigham (13, pp. 184-5), and the similar test employed by Wyatt (85, pp. 125-7). The responses, as well as the stimuli and the associations, are simplified by Healy and Fernald, who require the subject merely to designate the digits which are represented by the various sections of the diagram drawn by the experimenter, rather than demanding of him the active reproduction of some complex code message. In the Civil War code test, experimenters have found that the most significant process involved is, not the utilizing of a particular kind of imagery, but the need of an intense, purposive attention, inwardly directed for the analysis and association of the problem in hand. The improvement appearing with practice in the code test has been brought out by Dearborn and Brewer (25), requiring the subject to write long passages in terms of the code language.

Another group of related tests, generally called "cancellation" tests, require the rapid striking out, or cancelling, of certain letters, numbers, groups of letters or numbers, parts of speech, or other units, from a page of heterogeneous stimuli. As is evident from the summary made by Whipple (74, I, pp. 305-6), the psychological elements involved have been differently analyzed and interpreted by different experimenters; and this lack of concord may be partly due to the wide individual differences which, as Hollingworth (38) concludes, characterize performance in the test. A more elaborate form of test, using numerals, was developed by Taylor. The arabic numbers, from one to fifty, were scattered irregularly over the surface of a small sheet of paper. The subject then connected the numbers by drawing lines, beginning at one and continuing up to fifty; or in the form of this test used by Benedict, Miles, Roth and Smith (7), he simply pointed successively to the numbers in proper order. The use of spoken and written language in allied tests of association and discrimination occurs in such methods as the naming of colors or forms displayed successively; or the speaking or writing of words associated with those on a given list.

Various "motor coördination" and "dotting" tests are also related to serial action. In Dearborn and Brewer's (25) "Complex Dotting Test," each square on a sheet of coördinate paper bears a digit—one, two or three—indicating the number of dots to be placed therein by the subject. Woodworth's (80) subjects made efforts to strike rapidly in succession, with a pencil, the centers of squares, one-fourth inch in diameter, on coördinate paper. Following a suggestion from Whipple, the Healy and Fernald (33, p. 42) "Motor Coördination" test requires the placing of a dot in each of 150 half-inch squares on similar paper. In these tasks, simple discrimination and selective response are complicated by the need of precision of movement, and hence these tests seem to occupy a ground between serial action and the so-called "target" tests.

In considering the relation of these numerous "substitution," "code," "cancellation," or "coördination" tests to serial action, certain fundamental characteristics are found common to both the former and the latter. Broadly speaking, the entire group involves a "reaction" process, more or less analogous to that in the classical "choice reactions." Thus the "substitution" and serial action tests present similarities to the reaction experiments by Donders' "B" method, wherein each stimulus requires a selective reaction in accordance with a definite associative process. The "cancellation" tests demand repeated choice between movement and no movement, as in the Donders' "C" method. The more complex tests are usually types of "association reactions." In the code tests, however, the relationship is more remote: the stimuli appear *in toto,* as words or sentences, to be so retained, analyzed, and associated, unit by unit, with corresponding elements of some other retained, represented, analyzed and associated scheme, as to result in a series of appropriate complex responses. In this situation, the central process bulks so large and becomes so intricate as to minimize the parts played by sensory and motor factors. It is the bold features of these various tests which proclaim their relationship to reaction experiments; and they all vary from their prototype in the continuous, rather than isolated, character of the reactions demanded.

A second fundamental characteristic of the group is the demand for that "close attention and steadiness of purpose" which Healy and Fernald (33) found essential to the transliterating of words into a code in the absence of the code alphabet. As Woodworth and Wells (81) remark in their discussion of "measures of mental alertness," "In a test of either free or controlled associations calling for a series of responses in quick succession to a series of stimuli, the speed of the performance depends on maintaining the proper adjustment throughout the series, in opposition to the many interfering tendencies generated by the successive stimuli." A unity of purpose, signified by an alert attention, must bind together the concatenated responses. Distractions continually appear, whether caused by competing irrelevant letters, as in cancellation, or disturbing imagery, as in the code test, or the conflicting associations of the substitution test, or that anticipatory "set" which tends continually to assert itself with false prophecies, as in serial action. The efficiency and inefficiency of attention is reflected in all the tests by processes of "overlapping," and "interference"—the former characterized by a synthetic organization of the reactions, so that perception and discrimination of the new stimulus take place while the reaction to the previous stimulus is still under way; and the latter occurring when conflicting irrelevant associations accumulate and interpose with false leads, resulting in confusion and error. The successful performance of all these tests, therefore, involves a riveting of attention to relevant factors despite a host of distracting rivals. Accordingly, Meumann's (51, p. 393) insistence that the cancellation test is at bottom a measure of capacity for observation in line with a definite purpose, would largely apply to these related tests.

In comparing serial action, as outlined above, with these "substitution" and other related tests, certain general differences also appear. The fundamental distinction to be drawn is that, while the related tests involve various complications of attention, and of association and response, the serial action test strips the process of as many secondary and acquired features as possible.

Specifically, in serial action, the visual field presents to attention only one discrete stimulus, which cannot be succeeded by any other until a discriminative response has been made to it, while the other tests set the relevant stimulus in the midst of an array of foreign appeals, including the stimulus which will next demand a response. This simplifying of the situation in serial action becomes apparent also in a comparison of the characters of stimuli, associations, and reactions. In related tests, the stimuli consist of letters, symbolic designs, numerals, diagrams or other characters savoring of the academic. The real complexity of such characters, quite unrealized by the literate observer, becomes apparent when a totally illiterate subject faces the test, as occurred repeatedly when unschooled army recruits were helpless in dealing with the "Digit-Symbol" test. The tendency in the development of serial action tests has been to approximate the simplicity of the simple reaction, in choosing the visual or auditory stimuli. The associative processes, moreover, are to be stripped down to fundamental, natural coördinations. The object is not to measure the time required to form certain intricate, arbitrary associations, but to gauge the native efficiency of the subject in those associations which need only be pointed out in order to be permanently acquired. A similar contrast is apparent in the nature of the respective motor expressions. While the other tests employ such fine coördinations as occur in writing, and involve such uncontrolled variables as the extent, fineness and accuracy of pencil marks, serial action reduces the various responses to their simplest terms, following, once more, the character of the simple reaction. Thus, instead of employing the motor refinements of a single hand or member, serial action tests seek out the motor capacities of various members, in their simple, basic forms. And thus, while the "substitution" tests are of service chiefly in exemplifying the learning process, and while the "cancellation" test bears a somewhat complex and varying relationship to attention and perception, the serial action measurement takes its significance from its isolation of a basic "personal equation" in motor capacities.

Conditions Affecting the Time and Character of Serial Action Measurements

Before undertaking to standardize a test of serial action and harvesting data for comparative purposes, it is essential that the experimenter should appreciate the enormous number of variables, both objective and subjective, which are involved in any reaction test, and the extreme sensitiveness of the time measurements to every factor in the situation. On the basis of the multitudinous reaction experiments of the past fifty years, therefore, a summary of the chief conditions which have been found to play parts in the reaction process should be made, even though it be rough. In thus sifting the available data, the point of reference is, throughout, the applicability of these considerations to the particular type of reaction measurements involved in this investigation.

Objective Factors: (1) *The Stimuli.* Summaries of the relationships between reaction time and the quality, intensity, duration and extensity of the stimulus have been made by Wundt (83), Jastrow (39), Ladd and Woodworth (45), Todd (71), Henmon (35), Wells (73), and others. Thus in comparing the data from disparate senses, it is found that simple reactions to auditory stimuli are quickest; to tactual stimuli, intermediate; and to visual, longest. Wundt adds (83, p. 429) that the 'differences in the different senses disappear in the neighborhood of the threshold."

With reference to intensity, there is also some agreement. Wundt, (83, p. 428-30) found that the reaction time decreases rapidly as the stimulus rises in intensity above the threshold, but reaches a plateau where it remains constant despite greater intensity. Froeberg (30) laid down the law that, within the middle range of visual reactions, the reaction time tends to increase arithmetically as the intensity of the stimulus decreases geometrically; in auditory reactions, he found a somewhat proportional shortening of time with increase in intensity. Dunlap and Wells (27) did not entirely corroborate these relationships.

The size or extensity of the stimulus seems to be significant, Froeberg (30, p. 23-4) formulating the general law that the time of reaction increases with decreasing size of the visual stimulus.

Wundt asserted (83, p. 430) that, apparently, in all the senses a very brief stimulus produces a quicker reaction than one distinctly continuous. Froeberg (30) stated that the time of reaction increases with decreasing duration of the stimulus. In 1913, Wells (73, p. 59), using successively and not indiscriminately, auditory stimuli of various lengths, found that their duration did not materially affect the reaction times. The results of his visual experiments were equivocal, very small differences being apparent. However, the suggestion was that the reaction time decreased regularly as the duration of the stimulus decreased.

In considering the relation of the attributes of sensation to the time required for reactions, several experimenters have pointed to the "dynamogenic effect" of increased or diminished intensity, extensity and duration of the stimulus.

When the reaction involves a "cognitive" process in addition to perception, it is found that the cognition of qualities occupies a shorter time than that of intensities. The cognition of direction or position, whether visual, auditory or tactual, requires less time than that of the corresponding quality or intensity. Experiments show that the cognition of distance from our own body, by means of sight, consumes the same average time as the cognition of visual qualities. Various considerations are summarized by Külpe (44, p. 417).

The investigation of "discriminative" reactions yields proof that the discrimination of the positions of two or more stimuli is extremely rapid. Thus Bourdon (10) discovered that it was easier to perceive that a color was at the right or at the left of another color, than to perceive that it was identical with, or different from, another. Successive discrimination has, in general, been found more difficult than simultaneous discrimination.

However, in all "discriminative" reactions, the primary factor in the reaction time is the relative difference between the stimuli; a secondary factor is their absolute difference. The more similar the stimuli, the more difficult is the discrimination, and the longer the reaction time. In the words of Woodrow (78), "As the difficulty of discrimination varies, there is a variation in the corresponding discrimination reaction times." If the objective differences are decreased successively by equal amounts, the reaction time is lengthened proportionally, until the threshold of discrimination is approached. The explanation of this relationship seems to be two-fold: (1) If the stimuli are very similar, completer apprehension of them is necessary before the reaction can occur; and (2) under the more difficult conditions, the preparation to react quickly is less thorough-going, and innervation is not so completely accomplished.

Absolute differences between the stimuli are also significant in determining the time of discriminative reactions. From his experiments with the "chain reactions" of six subjects, wherein the particular reactions were determined by the discrimination of the lengths of lines, Münsterberg (53) found that the reaction times decreased somewhat as the absolute differences between the lengths of the lines were increased. He concluded that "for our subjective discrimination, therefore, the stronger effect of the relative differences of stimuli is constantly influenced by the weaker effect of the absolute differences in stimuli." Henmon (34, p. 53) corroborated this conclusion but found the influence of absolute differences not as pronounced as had Münsterberg.

The time of discriminative reactions having been found to vary in accordance with differences in stimuli, Cattell (18) proposed to apply the principle in a broad way as a new psychophysical method. As described by Henmon (35, p. 31), this method would proceed on the assumption that "differences in sensations should be equal if it takes equal time to perceive them, while if the differences are unequal, the greater the difference, the shorter the time of perception. By this method, it should be possible to arrange in accurate series, groups of differences in quality, or intensity, in every department of experience, simultaneously or successively perceived." As early as 1893, Cattell had applied this principle to the study of the time of perception of differences in intensity. Henmon (34) in 1906 carried the method into the fields of discrimination of differences in color, in the length of lines, and in pitch. He later asserted (35, p. 31) that "the fact shown in all these experiments that the discrimination reaction time varies uniformly with the differences to be distinguished, suggests the possibility of a wide application of the method in individual psychology, comparable with that of the association reaction already accomplished."

In the more complex discriminative reactions, such as those involving letters, figures or other symbols as stimuli, clearness of outline plays a very important role. Numbers require longer reaction times than do colors, or rectangles of various sizes, according to Bourdon (10). Any test based upon the discrimination of such stimuli lends a primary advantage to literate subjects, since they readily grasp the character of the symbols.

The greater the number of possible impressions, the longer is the reaction time. That this lengthening of the time is partly due to the process of distinction between the various impressions, and is not entirely dependent on the number of associated movements, has been shown by the use of "incomplete" or "subjective" methods, wherein the number of distinctions is varied while the number of movements remains constant. The experimental work of Cattell, Friederich, Tischer and others (39, p. 35) points to "a slight increase of distinction time with the increase of the range of impressions, but complicated with other factors as well."

In all reaction measurements, the latent time of the stimulus must be considered. A standard tachistoscope involves a latent time of perhaps 3 sigmas.

(2) *The Reaction Movement.* In spite of frequent criticisms, the telegraph key has been generally used for registering reactions (83, p. 390, footnote). Many other forms of keys and reaction movements have, however, been tried out. In his study of various reaction movements by means of graphic records, Williams (77, p. 102) found proof that "the form of key has a marked influence on the reaction time," and also upon the character of the attention.

Both the "lift" and the "press" type of reaction have been widely used. The former entails the disadvantage of frequently involving "antagonistic reactions." Williams (77, p. 149) found that "reaction time work which is done with the 'press' reaction will be free from the complications due to the antagonistic movement." On the other hand, Breitweiser (11, p. 46) concluded that the resistance offered by keys in the "press" reaction is an important variable, since, within certain limits, the greater the resistance, the longer the reaction time. For the "lift" form of movement, variations in resistance naturally affect the time only in a very slight degree. Breitweiser did not confirm Féré's conclusion that when the subject knows beforehand the weight to be encountered, the length of the reaction time will not vary with the weight.

The amplitude of the movement also has a bearing on the character of the result. In discussing reaction movements, Wundt (83, p. 390) states that "the combined movement of arm and hand, considering the natural use of which it takes advantage, is to be preferred, because it not only is accomplished the most rapidly, on the whole, but also may be repeated for the longest time without fatigue." The amplitude of movement, however, like the resistance offered by the key, must be strictly limited and uniform throughout a series of measurements, if fast and reliable reaction times are to be secured.

A certain excess force is usually exerted by the subject in making reaction movements, sometimes thus reflecting his habitual energy in responding to stimuli. Breitweiser (12) found, in his experiments with the variable in the manipulation of reaction keys, that the excess force "did not seem to vary in a marked or definite way with the resistance" of the key. This characteristic ponderosity and surplus force in the reactions of some subjects may point to individual differences in motor control which justly are reflected in lengthened reaction times.

Although wide experimentation has been carried on regarding the comparative reaction times of the two hands, universal agreement is lacking in the results of the various students. Tischer, Merkel and Cattell found the reaction time approximately the same for two hands. Poffenberger (59, p. 65) concluded, with respect to both Kiesow's data and his own, that "there is a difference in the reaction time of the right and left hands, in the subjects tested." He found (but with very slight difference) that in the right-handed subjects, the right hand is somewhat faster than the left; while the case is *vice versa* with the left-handed persons.

According to Henmon (35, p. 11), however, there seems to be general agreement that "in motor reactions, and in choice reactions, the differences are insignificant."

In measuring the reaction time of each of the five fingers, with simple reactions, Münsterberg (52) found that while at first the thumb and little finger reacted more slowly than the others, after some practice the times of all were substantially the same. Féré, however, gathered some data suggesting that the fingers making the strongest movements react in the shortest times. In 1910, Kiesow (41), using auditory stimuli, made a series of experiments on the reaction times of each of the ten fingers. Fifty reactions of the sensory type were made with each of the five fingers of each hand. The results showed that, in the right hand the speed of reaction of the fingers, from quickest to slowest, ran in the order: third, fourth, first, second and fifth. In the left hand, the order was: fifth, first, third, fourth and second. The differences between the respective times were very small throughout, while the mean variations ran from 13 to 19.5 sigmas. With respect to the relative speed of the fingers, the generally accepted point of view among experimenters has been that the reactions of unpracticed or slightly-used fingers are the longest.

As demonstrated by Merkel and others, the time of the choice reaction varies directly with the number of possible movements coördinated with corresponding sensory cues. If the difficulty of discrimination remains constant for all the series an increase in the number of choices, from two progressively to ten, lengthens the reaction time consistently until, with ten movements, it has been found to exceed the time for a "cognition" reaction by 300 or 400 sigmas. Külpe (44, p. 419) explains this result by the fact that "the degree of liability of reproduction and the quickness with which it is realized by connection in the particular instance, are certainly dependent upon the number of equally possible connections—and the greater their number, the greater will be the inhibition or retardation of the individual reproduction." It has been shown that if the associations between stimuli and movements be very natural and simple, an increase in the number of movements will not have a very marked effect upon the length of the reaction time.

From the experiments of Seashore, Coover, and McComas it is evident that, in tests of continuous discriminative reactions, the most convenient and satisfactory number of movements is four. Less than that number brings into consideration too high a degree of anticipation, while more than four movements has proved to be cumbersome and confusing.

Subjective Factors.—The character of the instructions and their manner of presentation are profoundly significant for the performance; and this importance extends to the minute details of phraseology as well as to the main principles given to guide the subject's behavior. The wide differences and the high variability shown in many reaction measurements are partially due to the variations in the completeness, the emphasis, and the clearness of the directions. The continual use of spurs—such as telling the subject the best time he has made, or encouraging him to break another individual's record—is extremely effective.

Closely bound up with the general character of the instructions is the "charge," or the degree of effort induced into the subject's attitude. By proper suggestion, the energy and application of the subject can be maintained at a maximum. While a certain tedium or monotony appears in reacting to isolated stimuli, continuous reactions call out a spontaneous and sustained interest; as McComas (49) remarks, the subjects consider it "fun" to plunge into the test and rush through the ever-changing series of responses.

The great importance of expectation on the part of the subject has been emphasized by Wundt (83, p. 435) and others. For fast and steady reactions, the reagent must be familiarized thoroughly with the stimuli. Jastrow (39, p. 39) formulated the general law that "the more definite the foreknowledge of the subject, the quicker the reaction." The increase in time when any factors relative to either the stimuli or the responses are not explicit has been made very patent by various cognition and discrimination experiments. Anticipation is inextricably interwoven with expectation in the subject's attitude; that is, he not only knows the characteristics and details of his prospective task, but also predicts the precise nature of each next-appearing stimulus, and prepares a corresponding reaction. Out of such forecasting develop premature, delayed and wrong reactions. Some preliminary trials are usually necessary, in order to clear up and define the subject's expectation. These initiatory reactions at the same time can supply the place of the "shock-absorbers" suggested by Link (47, p. 155) for introducing the subject to the test.

That the time of reaction is a function of the degree of attention has long been a demonstrated fact. Thus Dallenbach (23, p. 507) states that "introspectively distinguished variations of attention (*i.e.*, clearness) are closely paralleled by corresponding differences at the same level in accuracy of work performed, in rate of reaction, and in degree of precision as expressed by the m.v." So intimate and regular is this dependency that the time of reaction has been used by Woodrow (78) for measuring degrees of attention.

The complex reaction is considered by some experimenters to involve a nicer concentration of attention than does the simple reaction. Thus Henri (37, p. 245) proposed the use of discriminative reactions for the study of attention, pointing out that the "mean variation, the time, and the irregularities in the curve of reactions will give a relative idea of the state of attention with the subject."

Out of the long dispute regarding the real significance of the "direction of attention" in simple, and also in complex reactions, there has grown general agreement that, as Woodrow (78, p. 14) declares, "a time measurement cannot be a satisfactory measurement of efficiency except when the work is done with the sole idea of doing it as quickly as possible; as, for example, in the case of a 'motor' reaction." Among the chief objections to the use of "sensory" reactions in the tests may be mentioned: the complication of the reaction by adding observing to reacting (Breitweiser); the fact that the sensory form tends to change with practice to the motor form (Ach); the varying degrees of determination to react as quickly as possible (Ach); the ambiguity of the instructions, which leave to the observer the task of determining the promptness with which to react (Woodrow).

Somewhat analogous are the objections to the use of any possible "sensory" form of complex reaction, as suggested by Münsterberg. It is indeed evident that in reactions after discrimination and choice, the attention should be bound down to specific functions, which cannot well be varied: First, for discriminating the particular sensory impression received; and second, for inaugurating the appropriate movement. This delimitation of attention is particularly effective in ordinary complex reactions because: (1) the performing of each reaction is a discrete problem, preceded by a definite preparatory stage; (2) the associations of stimuli—such as colors, words or sounds,—with movements are usually somewhat artificial; and (3) the number of reactions made is not usually great enough to stamp the characteristics of an automatism—or "automatic coördination" upon the performance.

Investigations of the function of attention in continuous discriminative reactions have shown that some modifications of the attentive process appear. Instead of consisting of an aggregation of isolated reactions, each characterized by the preparation and sharp focalization of attention, the whole series of movements becomes unified by a common purpose and by an habitual attitude, just as in the fused serial actions of daily life, like reading or playing a musical instrument. Experimenters therefore find an "overlapping" process occurring, by which a flow, rather than a chain, of reactions takes place. The discriminative and the volitional processes in the subject's responses are somewhat "telescoped." In this kind of serial adjustment, "interference" also appears, as the associations accumulate. The attention moves along, with the consciousness of new stimuli impending over the present responses, and a varied finger-play accompanying the shifting signals. Thus a "motor" type of attention develops, in an efficient subject: that is, an attention directed predominantly neither to stimuli nor to reacting members, but to achieving a seriated adjustment as rapidly as possible.

In continuous reactions, furthermore, the number of reactions usually aggregates so great a total, that "automatic coördination" develops, and attention is liberated for dealing more synthetically with the discriminative and selective processes.

As analyzed by Külpe (44, pp. 418-19), the certainty of the association between impression and movement may be (1) originally given as a result of previous individual development; (2) consciously effected by practice, or (3) involuntarily produced by repetition in the course of the experiments.

The associative connection of reaction movements with definite directions in space is particularly easy, making use, as it does, of previously developed habits. Bourdon's (10) experiments with colors, numbers, and sizes, in which reactions were made by the right or the left hand to the corresponding one of two stimuli, showed in a marked way the "close association which exists between the sensation at the right and the movements of the right hand, or between that at the left and the movements of the left hand." He found, for example, that if the association be reversed, and the stimulus at the right be reacted to with the left hand, the reaction times were, on the average, 50 sigmas longer. The direct association of position with hand was found to be so strong that reaction with the right hand to a red stimulus when it appeared at the right was just as rapid as a simple reaction to red. He concluded that "there exists normally an intimate association between the sensation at the right (or left) and movements of the right hand (or left). Ordinarily, when we grasp an object situated at the right, it is with the right hand." Anatomically, as Poffenberger (59, p. 64) points out, the right hand is most directly associated with objects in the right visual field—that is, with the left-half of the retinal field of each eye.

The simpler and more natural the association between stimulus and movement, the shorter the reaction time. Thus Münsterberg (52) found that the reaction times for the five fingers, when associated respectively with the numbers 1, 2, 3, 4, and 5, were considerably shorter than the times of the same fingers when associated with the declensional forms of a Latin noun. Simple associations also involve less probability of the entry of superficial or adventitious complications; and they lead to better initial performances and less pronounced improvement curves than do the more complex types.

Although the subjective factors in reaction measurements be standardized as thoroughly as possible, yet more or less pronounced inherent differences in the attitudes of subjects continually appear. In accordance, perhaps, with Meumann's (50) twofold classification of reagents—the "impulsive" type, persons of will, whose motor development has been vigorously extended, and the "intellectual" type, consisting of the observant and reflecting group,—subjects seem to fall naturally into either of two characteristic attitudes, when continuous discriminative reactions are undertaken: they either actively "push" the signals along by means of vigorous reactions, or else passively follow their beck and call. The experimenter puts a premium on the former type of reagent. This stress upon the greatest possible speed must be tempered by a recognition of the difference in native capacity and habitual performance. Some allowance or "leeway" must be granted the subject, in the direction of Stern's (67, p. 86) position: "For differential psychology, 'maxima' are not unimportant, but much more significant for it are 'optima'; that is, such performance-values as are indicative of the natural inner disposition. The method followed in the latter cases runs thus: 'make your behavior now what seems most natural and agreeable.' Not the fastest rate of speed that an individual can attain under the pressure of great haste, but the natural pace which he selects for proceeding, when he is not subject to temporal considerations, is indicative of his temperament."

Practice and Fatigue.—The time of both simple and complex reactions decreases with practice, rapidly at first, but tends soon to approximate a limit. The greatest decrease occurs in the time of those processes which are most complex and of greatest initial duration. The "sensorial" form of reaction shows the greatest improvement in speed, and its character at the same time seems to approach that of the "motor" reaction (Wundt 83, p. 419). In their study of the types of reactions, Angell and Moore (3) found that "continued practice in the two modes of coördination with a constant stimulus, under constant conditions, results in two highly reflexive forms, not of widely different, but of about equal time values." The "motor" reactions remained a little the faster.

With practice in simple reactions, a kind of "automatic coördination" of impression and reaction develops. Following longer practice, the same coördination is built up in complex reactions, thus gradually eliminating the psychical processes and giving to the reactions a generally physiological significance. Wundt (83, p. 471) found that this tendency toward automatism develops most readily in persons of naturally "abbreviated" mode of reaction. It appears most rapidly in those experiments where the number of impressions and of movements is small, and the associations between them are natural.

Diversity of opinion reigns with respect to the influence of practice upon individual differences. The experiments of Wundt (84, p. 222) and his collaborators, especially Alechsieff (1, p. 15 ff) led the former to conclude that "when the experiments are carried out with proper care, these individual differences (which belong to the discussions of psychological characterology) disappear more and more. As the individual differences disappear, the influence of the variable conditions, such as differences in preparation and in the direction of attention, become clearly apparent."

On the other hand, the experiments of Henmon and Wells (36) showed the persistence of distinct individual differences in the simple and complex reactions of two long-experienced subjects. "Of the fact of these individual differences, preserved long after practice could essentially change them, there can be no dispute. . . Distinct individual differences also exist in the discriminative or choice reactions, but in the opposite direction from those of the simple reactions."

In reaction experiments, fatigue manifests itself through a lengthened reaction time, greater variability, fluctuations of attention, and, in complex reactions, an increased number of errors. Since the first investigations of Exner (29) upon the effects of fatigue, the improvement in performance due to practice has been regarded as somewhat offset, in any continued series, by a deterioration due to fatigue.

The extent of this decline in efficiency, when long series of reactions have been made, has generally been found to be relatively small. Cattell (17) conducted a number of experiments to determine the precise effects of fatigue. In the most thorough-going of these, 1950 reactions, consisting of a combination of different groups of reactions—to light, white surface, letter, association and sound—were made without interruption during the day, from 8:30 a. m. to 11 p. m. in B's series, and to 1:30 a. m. in C's series. Only very slight changes attributable to fatigue were apparent in the results. Similarly Patrizi's (55) series of tests, in which only two seconds intervened between successive reactions, showed a very slight lengthening of time and increase of variability. From allied experiments, Woodworth (80) concluded that the central apparatus for the precise adjustment of a movement is susceptible to fatigue, but only slightly so.

Cattell found that the most automatic processes were the least affected. To determine the rate of fatigue of different factors—attention, accommodation and convergence—Scripture (60) produced flashes in a Geissler tube, at regular intervals, and the subject pressed his key in response to each flash. It was concluded from the experiments that "the fatigue in reaction time increases with the complexity of the adjustments required for perceiving the stimulus," and that "the tendency to fall into a condition of daze depends on the fact of repetition of stimulus (fatigue of attention) as well as fatigue from adjustments."

The analysis of achievement in two-hour periods of continuous reactions led Oehrn (54) to conclude that, first, occurred a stage in which practice outweighed fatigue, and then a stage wherein fatigue was dominant. On the basis of their immense number of experiments—particularly with the continuous addition of columns of digits—the Kraepelin school analyzed the "work curve," finding characteristics which generally are applicable to serial action. Fundamental in every continuous process, they held, were the effects of practice and fatigue—immediate effects, and permanent effects. Among secondary factors were the preliminary incitation (Anregung), the preliminary spurt (Antrieb), a fall preceding the best achievement of the work-period (Ermüdungsantrieb), a periodic succession of spurts and falls in performance (Willenspannung and Störungsantrieb), and a final spurt (Schlussantrieb) occurring if the subject discovered that he was near the end. An analysis of each of these processes was attempted. "Variations in attention" were seen in the wave-like periods extending, from crest to crest, over about 2 3/5 seconds.

An intensive study of the characteristics of continuous mental work involving (1) sensitivity, (2) discrimination and (3) memory, was made by Seashore and Kent (64) in 1905. The general conclusions drawn from three widely divergent series of experiments were: "A thorough-going periodicity of mental activity" was found. "There is a continuous gradation from the period of the momentary active impulse up to the hour-long waves of mental efficiency. The efficiency in a given period, say two hours, may be represented by an irregular wave, the resultant of a series of partials." Three kinds of waves were found: (1) second waves, extending over not more than a few seconds; (2) minute waves involving more than one second wave, but less than 20 minutes long; (3) hour waves, whose periods lie between the minute waves and diurnal waves. In all continuous work, progressive change, with respect to time, accuracy and variability, is found.

Individual types in efficiency of continuous work have been described by Kraepelin (43). Five typical kinds of "work curves" were discerned: In the first or "positive" curve, practice dominates the performance to the end of the two-hour tests given; in the second, fatigue is the dominant factor throughout. The third form of curve follows the trend of the first, but shows fatigue effect opposing the spurts of improvement. The fourth type illustrates the counter-balancing of practice and fatigue; while the fifth includes characteristics of the other types except the second.

In an unpublished study of mental fatigue by the use of the Seashore psychergograph, Florence Brown Sherbon at the University of Iowa in 1904, made a continuous series of "choice" reactions, totalling 16,000 in number, in one period of four hours and fifteen minutes. Characteristic of the time curve were: a high initial speed, a long period of constancy, a heavy drop in speed after 10,000 reactions, followed by considerable variability until the end of the "work." The number of errors increased and became more variable as the test progressed, to the close.

In his investigation of the accuracy of various observers in continuously performing a certain series of calculations mentally, and registering their results by means of a lip or finger-key, Yoakum (87) found a "fluctuating character" in the totals of errors per minute, the errors tending to group themselves. The error-groups persisted throughout practice; and were interpreted as evidence against "the possibility of considering mental work as anything apart from specific, coördinated, muscular responses." A condition of strain continually appears, and the shifting of the seat of the 'strains' leads to the production of a new center for the 'vis a tergo' sensations. This periodic transition shows—as is generally evident in consciousness—that "a center of kinaesthetic activity is calling for readjustment." (87, pp. 108-10.)

From his own experiments in distributing the physical expression of the work among various members, such as the fingers and the lips, and from related experiments of Lombard and Hall, Yoakum (87, p. 107) concluded that "as a theoretical result, the fluctuations in errors, and mind wandering may perhaps both be largely eliminated by the arrangement of a series of tests that alternate the processes used in tapping the records. Thus the habitual working rhythm of the various subjects could be eliminated so far as concerns an inferior quality of work appearing at certain periods."

Apparatus and Method

The apparatus used in the following experiments consists essentially of a commutator attached to a typewriter in such a manner that every movement of a key on the typewriter completes one of four possible circuits, the order of appearance being determined by chance for a series of seventy-five reactions. In these four circuits may be placed any series of four stimuli, such as colors, forms, words, lights, tones, or noises. Four keys of the typewriter, in the middle of the keyboard (such as y, t, u, i, or 5, 6, 7, 8), are so marked as to be distinguishable, to both sight and touch, from the other keys. Each of the four keys is associated with one of the four stimuli. The subject then places four fingers—the index and middle fingers of both hands—lightly on these keys, and proceeds to make an unbroken series of "reactions after discrimination and choice," in the following manner.

Assume that the four keys, designated for convenience as 1, 2, 3 and 4, are associated respectively with four tonal stimuli of the same pitch, intensity and timbre, located in four easily discernible directions, 1, 2, 3 and 4. The experimenter then inaugurates the "work" by turning on the current, thus causing a tone, for example, in direction 2. The subject must identify this signal, and press the corresponding key, 2, as quickly as possible. By the consequent action of the typewriter carriage, the commutator is moved forward a step, and immediately produces the next signal, *e.g.*, 4. In response, the subject must press key 4, thus causing the appearance of the following signal. In the same manner, signal follows signal, each with its appropriate reaction, to the end of the line—seventy-five spaces. Meanwhile the typewriter keys have recorded the successive reactions, so that they can be checked over for accuracy.

Time is kept in gross for each line, with a stop-watch; or for certain purposes a graphic recorder is wired with the keys in such a way as to furnish a graphic time and error record for each act. Or, the starting and stopping of the stop-watch may be mechanically controlled by attaching its lever to the armature of a magnet which is so connected that the circuit through it is closed while the reactions are in progress. For most purposes, this is an unnecessary refinement.

The commutator consists of a brass plate (A, in Figure 1) which has seventy-five insulated contacts, arranged in four rows, with a contact brush (B) running in a groove over each row.

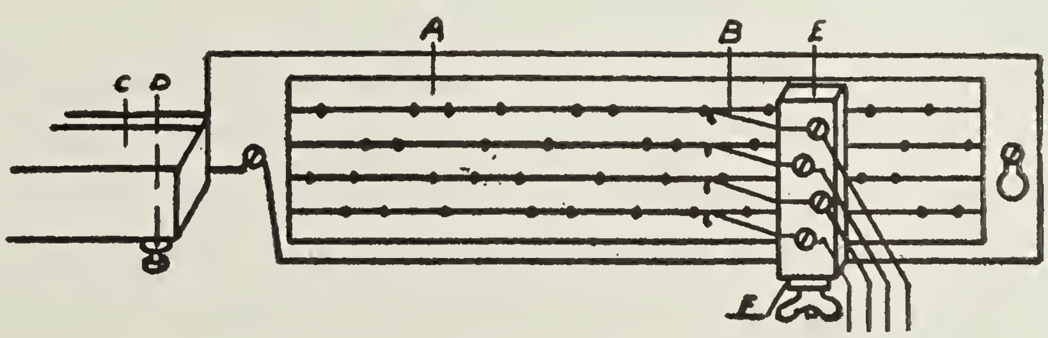


FIG. 1. The commutator

A. Brass plate, overlaid with fiber surface.
B. Contact brush, of spring-brass wire, running in grooves,
C. Clamp attaching commutator to stem of typewriter.
D. Common terminal through body of typewriter.
E. Block of fiber bearing the brushes.
F. Clamp attaching block to carriage of typewriter.

The commutator plate is attached by a clamp (C) to the back stem of the typewriter, with the contact-surface facing away from the subject. In these experiments, only Remington machines were employed; for use on other kinds of typewriters, the form of the clamp would have to be modified. The brushes (D), made of spring-brass wires, are fastened through an insulated block of fibre (E) attached by a clamp (F) to the carriage, so that with each stroke of a key the brush-carrier moves one step forward, thus shifting the circuit to a new line. In the arrangement of the contacts, a chance order is followed, except that no line is allowed two successive stimuli; and an equal number of contacts, with one exception, occurs on all the lines.

The wires attached to the four brushes lead to the corresponding terminals upon the signal apparatus, and each circuit is then completed through a battery, a rheostat, and the base of the typewriter. The current used in these experiments is simply taken from the 60-cycle, 110-volt alternating current which is the source of illumination in the university buildings. Beside being always available, this alternating current, when placed directly in circuit through telephone receivers, gives rise to a low, steady tone of pleasing timbre and uniform intensity. The rheostat is introduced in order to cut the voltage down for both visual and auditory experiments. A switch under the experimenter's hand enables him to produce the first stimulus precisely when desired.

The commutator and other apparatus used in the following experiments were so simple and reliable that they operated daily for many hours, during several weeks, without irregularities. Other commutator-standards, giving new orders of the seventy-five stimuli, could readily have been made, and substituted in the attachment without difficulty; but, for tests wherein each subject was given only 5 or 10 trials, such changes in order were deemed unnecessary.

As finally developed, after many preliminary experiments[1]

[1] Five kinds of stimuli were tried out and finally discarded in favor of the two described above. Auditory-motor tests based upon intensity differences were made, by mounting a single telephone receiver directly in front of the subject and so wiring the commutator brushes as to produce four tones of widely different intensities. In producing these tones, the primary circuit, which led through the commutator, was interrupted by a 100 dv. fork. The brushes were wired with coils of varying inductance, so that the secondary circuits which were induced and conducted through the receiver, produced four tones differing only in intensity. The subject was instructed to respond to the weakest tone by pressing the key farthest to the left; to the next in intensity he pressed the second key, etc.

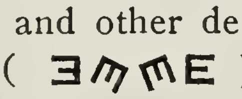
The experiments with pitch differences were made with electric bells of widely varying pitch. The subject simply associated the four tones, from lowest to highest, with the four reaction keys, from left to right. Timbre differences were produced by varying the richness of the tones in four uniform bells, telephone receivers, or buzzers.

The auditory stimuli used in the first extensive series of tests were noises produced by four small electric buzzers located exactly as the telephone rethe stimuli for these experiments were of only two kinds: auditory and visual, both demanding discrimination of position for the reactions of the subject. The signal apparatus for the auditory series consisted of four ordinary telephone receivers located respectively 90° left, 30° left-front, 30° right-front, and 90° right, in the horizontal plane of the ears, each at a distance of 45 cm. from the center of the subject's head. "Confusion points" in localization were avoided by this arrangement, and very little difficulty in the discrimination of the source of sound was ever reported. The low, even tones induced by the alternating current furnished very definite sensory stimulation to any subject of normal acuity. The intensity of the tones was such as to render them easily audible within a radius of four meters.

In their final form, the visual stimuli consisted of four ordinary candelabra electric lights, mounted side by side directly in front of the subject's eyes, in a horizontal position. The four reaction keys were then naturally associated by the subject with the four corresponding lights, in order, from left to right. The candelabra globes had been frosted; and when mounted, the distance between the centers of the two outside lights was 12 cm. They were located at a distance of two meters in front of the subject, and a large black background eliminated reflection or other distracting factors. By these arrangements, accommodation and convergence were easy and natural, and movements of the eyes in following the shifting lights were minimal.

Since the alternating current used was the same as that employed for auditory stimuli, a simple switch was introduced, by

ceivers described above. The buzzers were padded and tightened in such a manner as to equalize roughly their intensity.

For visual stimuli, a wooden screen in the center of which was an aperture 1.3 cm. in diameter was set just above the typewriter, facing the subject. Four electric magnets were so screwed to the reverse side of this screen, that the prong attached to the armature of each, bearing a small disc, was drawn before the aperture whenever the circuit was closed; when the circuit was again shifted, the particular disc withdrew, to be succeeded by another. After some experiments with colors and other designs, for use on the four discs, the letter E in four positions () was chosen. They were associated in that order with the four keys.

which the current could be shifted at will from one mode of stimulus to the other. As all the tests were given by daylight, and the lights seemed more intense on dark days, the resistance of the rheostat was varied slightly from day to day. Very few subjects ever complained of eye-strain; a few found the after-images slightly annoying.

For one short series of tests, the commutator was eliminated altogether, and the method suggested by Coover and Angell—attaching a strip of typewritten digits to the carriage and thus exposing the digits successively through an aperture in the screen—was followed. The digits used in that series were 5, 6, 7, and 8.

Three general considerations favored the use of the tones and the lights as stimuli: the great ease of discrimination; their reliability for long-continued, uniform work; and their non-fatiguing character. The sensory discrimination was basic and immediate; the association with movement was almost equally natural.

The reaction movement consisted, throughout, of pressing the typewriter keys—5, 6, 7, and 8—with the fingers which were placed over them. Two groups of variables were here involved, due (1) to the character and condition of the typewriter, and (2) to the previously acquired skill, or the lack of skill, of the subjects in typewriting. Among the variables of the first class were the "make" and model of machine used, the amplitude of movement of the keys, the amount of use or misuse which it had undergone, the degree of lubrication, and the tension or "springiness" of the carriage-movement.

There was, accordingly, an extensive latent time in the successive stimuli, and in the registering of the reactions. The greater part of this latent time was due to the mechanism of key and carriage. As a consequence, the reaction times were not comparable with those recorded by any former investigators of complex reaction times. But, since this latent time, in spite of its extent, was constant and uniform throughout any series of tests, the reaction times were certainly of relative value, and exhibited the individual differences in those times with great reliability.

The extent of previous training in manipulating typewriters was also considered. Unskilled subjects were coached on the proper use and economy of energy in their reactions, since some were prone to waste time on ponderous movements, while others did not strike the keys heavily enough to record the reactions. The subject kept all four fingers constantly in touch with the surface of the proper keys, so that time would not be consumed in movements to establish those contacts when they became necessary. In general, however, all subjects, even twelve-year-old children, who were experimented with, found the reaction movements simple enough to liberate their attention for the work as a whole.

The procedure followed in giving the tests was directed toward securing the subject's maximum achievement in speed, together with reasonable accuracy—not more than five errors in one trial. When the subject was seated comfortably before the typewriter, in a position free from awkwardness or strain, he was told to place the index and middle fingers of both hands upon the four cloth-covered keys. Then the experimenter pointed to the lights (or telephones, if the test was auditory), and said: "You see these four lights. When this first light comes on, press this finger (pointing); when this second light appears, press the second finger," and so forth.

The current was then turned on and the subject was introduced to the task by reacting successively to about twenty-five stimuli, the experimenter encouraging him and watching his fingers to verify their accuracy. Then, during a pause, the complete instructions were given in colloquial language:

"This is a test of speed and accuracy. Throw every effort into the work so as to make the very best time that you possibly can, with approximate freedom from error. After you begin a line, do not let anything stop you or confuse you even for a fraction of a second. Time counts.

"Work at such speed that you will not make more than five errors in a line. This is a standard of certainty which should determine your speed. You can fail by being over-cautious and slow or by being reckless and fast.

"Now prepare yourself for the movements. Be on the alert all the time, to move. Push the lights. The faster you push them, the better your record will be."

This emphasis on a "motor" form of attention was continued through the test. At the end of the practice trial, the experimenter asked, "Are you making many mistakes?" and proceeded to compare the record with the key. Complimenting the subject on either his speed or his accuracy, as the case might justify, the experimenter said: "Now we want to get ten records from you." The warning "Ready," was given from one to two seconds before each trial began. The stop-watch in the left hand was started simultaneously with the turning on of the current with the right hand. When the last stimulus of the trial appeared, the experimenter directed his attention to it, and stopped his watch immediately following the reaction which extinguished it.

The intervals between the successive trials were simply long enough to permit the experimenter, assisted, perhaps, by the subject, to check over the record for errors. If less than five errors had been made, the subject was complimented; if the trial contained more than five errors, he was advised to "cut down the mistakes a little next time." The subject was kept informed of his time in seconds for each performance; and his "best record so far," or the "highest score of anybody today," was emphasized. A competitive attitude and an ambition to "cut the time down a little more" were encouraged. The experimenter, however, constantly sought to avoid a stereotyped, or "professional" habit of giving encouragement.

For some types of subjects, this continual prodding was highly successful. Many persons began with ease and composure, by assuming a very moderate pace, one which represented a fairly low level of their potential rate. Repeated spurring, with the incentives of pride and competition, simply aroused such habitually low-geared persons to keener effort and higher efficiency.

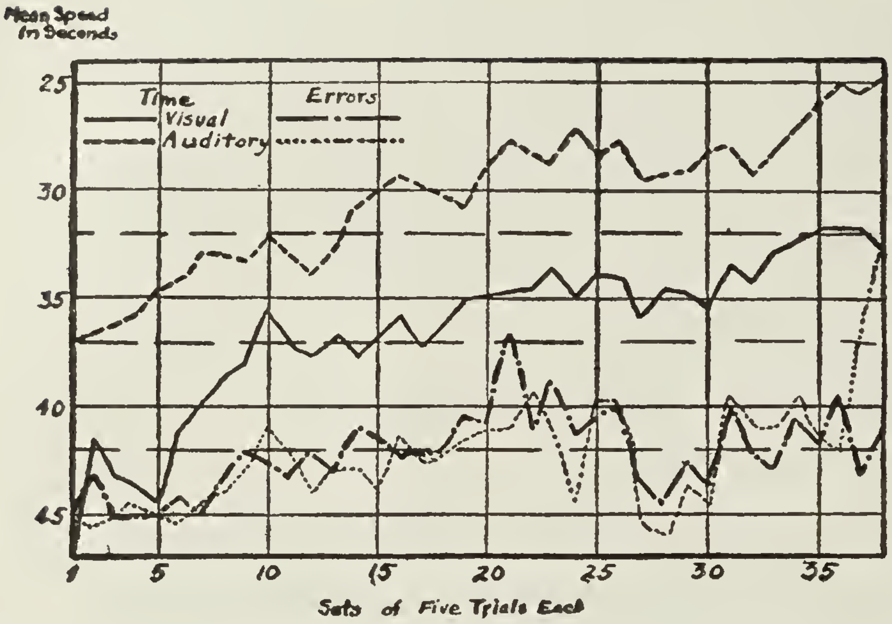
On the other hand, some subjects, naturally "high-strung" or tense, selected an *optimum speed*—one representing that rate of performance which they had generally found most successful. This habitual gait, timed in accordance with natural motor capacities or long motor experience, could not be broken without a serious loss of efficiency. Undue pressure simply resulted in their "going to pieces," losing the coördinations, making long series of indiscriminate responses, or pausing in complete confusion. Instead of "rising to the occasion," they were "rattled" by the demand for unusual self-control. Accordingly, some caution was exercised in the use of suggestion.

The Effects of Practice upon Performance in the Test of Serial Action

In order to determine the effects of practice upon performance in serial action, three groups of experiments, involving tests with five different kinds of stimuli, were undertaken. Since, during each of these practice series, no substitution or change of commutator standards was made, the order of the seventy-five stimuli remained exactly the same throughout. Consequently the improvement curve includes as a significant factor the gradual acquisition of the order of stimuli and reactions.

In addition to this increasing retention of the sensory and motor sequence, the learning process involved the attainment of "automatic co-ordination." A fast, rhythmic rate of reaction, economizing both time and energy, was built up, and the experimenter did not usually interfere with this steady gait even when more errors than the instructions permitted were left in its wake.

Series A.—The first of these experiments, Series A, consisted of an intensive investigation by Mr. H. R. Fossler, of the effects of practice. Each subject—all being university students—reported every third day for a considerable period, on each occasion taking first a set of five trials with visual stimuli, then a set of five trials with auditory stimuli, and alternating thus until three sets with each kind of stimulus had been made, resulting in a daily total of thirty trials. Subject A was thus given a total of 190 trials with each kind of stimulus, and his practice period involved the making of 28,120 individual reactions. Subject B totalled 130 trials each of visual and auditory reactions, with 19,240 individual responses; and Subject C made 60 trials including 8880 reactions.



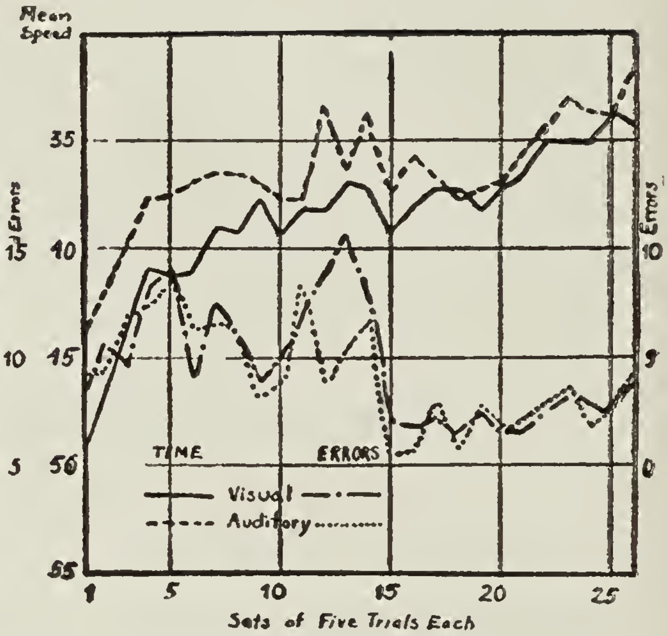
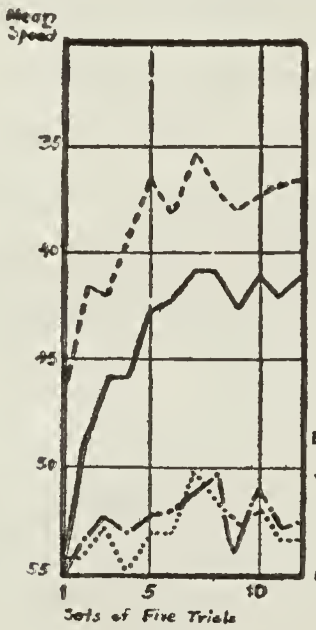


Fig. 2. Practice curves of subject A in speed and accuracy.
Fig. 3. Practice curves of subject B in speed and accuracy.



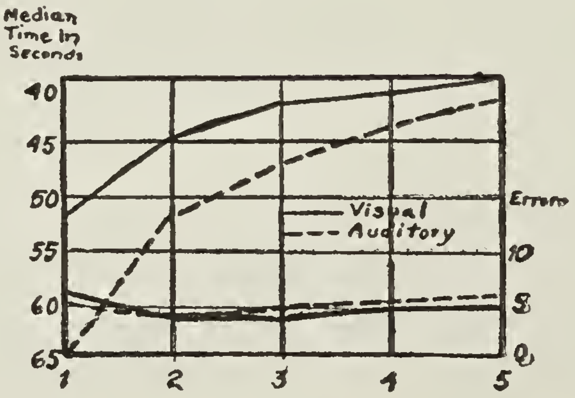


Fig. 4. Practice curves of subject C in speed and accuracy.
Fig. 5. Practice curves of speed and accuracy, 26 subjects.

Figures 2, 3 and 4 indicate the progress of this practice series in terms of mean speed in each set of five trials. A steady improvement in speed is apparent in all cases from the first set onward, with but few hesitations and plateaus. For subject A, the mean time of the thirty-eighth set was 34.2% faster than that of the first set in the auditory series, and 31% faster in the visual series. Similarly, the final record of Subject B was 27% faster than his initial set, in the auditory, and 32% in the visual series.

Inspection of the curves denoting the number of errors reveals a fairly consistent decline in accuracy concomitant with the increase in speed, except after the fourteenth set of Subject B. This relationship is expressed by the correlation coefficient r, .87, p.e., .03 between speed (from fast to slow) and the number of errors, in the auditory series, and r, .77, p.e., .05, in the visual series, of Subject A. The corresponding coefficients for B are negligible, on account of irregularity in procedure. Subject C agrees with Subject A.

It was found that relatively "good sets," as well as "good days" in performance with visual stimuli were generally also "good" with the auditory. This was true of both speed and accuracy. The high speeds in the visual series were usually followed by correspondingly high scores in the auditory series, this correlation between mean speed in the visual and auditory sets being r, .93, p.e., .03 for Subject A, and r, .74, p.e., .08 for Subject B. The corresponding pairing of accuracy in the visual and auditory sets is shown by the coefficients r, .70, p.e., .05 and r, .90, p.e., .03 respectively for Subjects A and B, while Subject C, whose record is not so extensive, also supports these relationships.

Series B.—Twenty-six students in the Northwestern University School of Music, all girls, composed the second group of subjects for the study of practice in serial action. This investigation was made by Dr. E. A. Gaw. On each of five days, at intervals of from three to seven days, two sets of tests were given to each subject, the first set consisting of five trials with visual stimuli, and the second of five trials with auditory. For the former, the four digits, 5, 6, 7, 8, typewritten in chance order on a strip of cardboard, and exposed, one at a time, through an aperture in a screen following the method suggested by Coover and Angell, were used. The auditory stimuli consisted of tones produced by telephone receivers as previously standardized.

An effort was made to control the number of errors more completely than had been the case in the previous experiment. At the beginning of each day's work, each subject was told what her average record, in both time and accuracy, had been on the previous day. If the average number of errors had exceeded five, the subject was cautioned on the following day to be more accurate. If she had been painstakingly accurate at the expense of speed, she was urged to work for more speed. Figure 5 shows the median speed of the entire group of subjects, with both visual and auditory stimuli, for each day. These medians are figured from the means of the individuals' five daily visual, and of their five daily auditory trials. A similar procedure is followed with respect to the errors.

Pronounced improvement in both visual and auditory series is evident during the entire period, as is shown in Fig. 5. The last day's speed is twenty-five per cent faster than the first day's, in the visual series, and thirty-seven per cent faster in the auditory. The subjects thus make more improvement in the twenty-five trials given, than did the subjects in Series A in the same number of trials; but the latter had made these reactions all in one day rather than at intervals for five days.

In the twenty-five trials given (as also appeared in the first part of the previous practice series, with Subjects A and C), accuracy did not decrease with the acceleration of speed in reacting. The series of tests was not extensive enough to determine whether or not this uniform degree of accuracy had become a permanent characteristic of the subjects' reactions.

A comparison was made of the ranks of the twenty-six subjects on the basis of speed on the first day, and then on the basis of mean speed for all five days. The correlation between these ranks was r, .88, p.e., .03 in the visual series, and r, .89, p.e., .03 in the auditory, thus showing that the first day's performance generally gave a fair index of the potential speed of the subjects. The correlation between rank on the first day and that on the last day was r, .76, p.e., .07; and r, .63, p.e., .09, respectively, in the visual and auditory tests.

The ranks of the subjects on the basis of their speed in reacting to one kind of stimuli corresponded only roughly with their ranks when using the other kind of stimuli. This correlation between ranks in visual and auditory scores on the first day was r, .48, p.e., .11; and the correlation between visual and auditory rankings based on the total achievement of all days was r, .52, p.e., .11.

Series C.—The third series of practice tests was given to six students, all men, each of whom was given ten trials on each of seven successive days, reacting to the candelabra lights as stimuli. On every day, each subject was encouraged to try to surpass not only his own best record, but also the record of the fastest man. As the tests progressed, the number of errors increased, and in spite of repeated cautioning, tended to gain in number from day to day. In the later days of the series, several subjects remarked that the errors seem bound to come, whether they tried to slow up and be careful, or not.

The mean time for the ten trials of each subject on each of the seven days is shown in Figure 6. From this figure it is seen

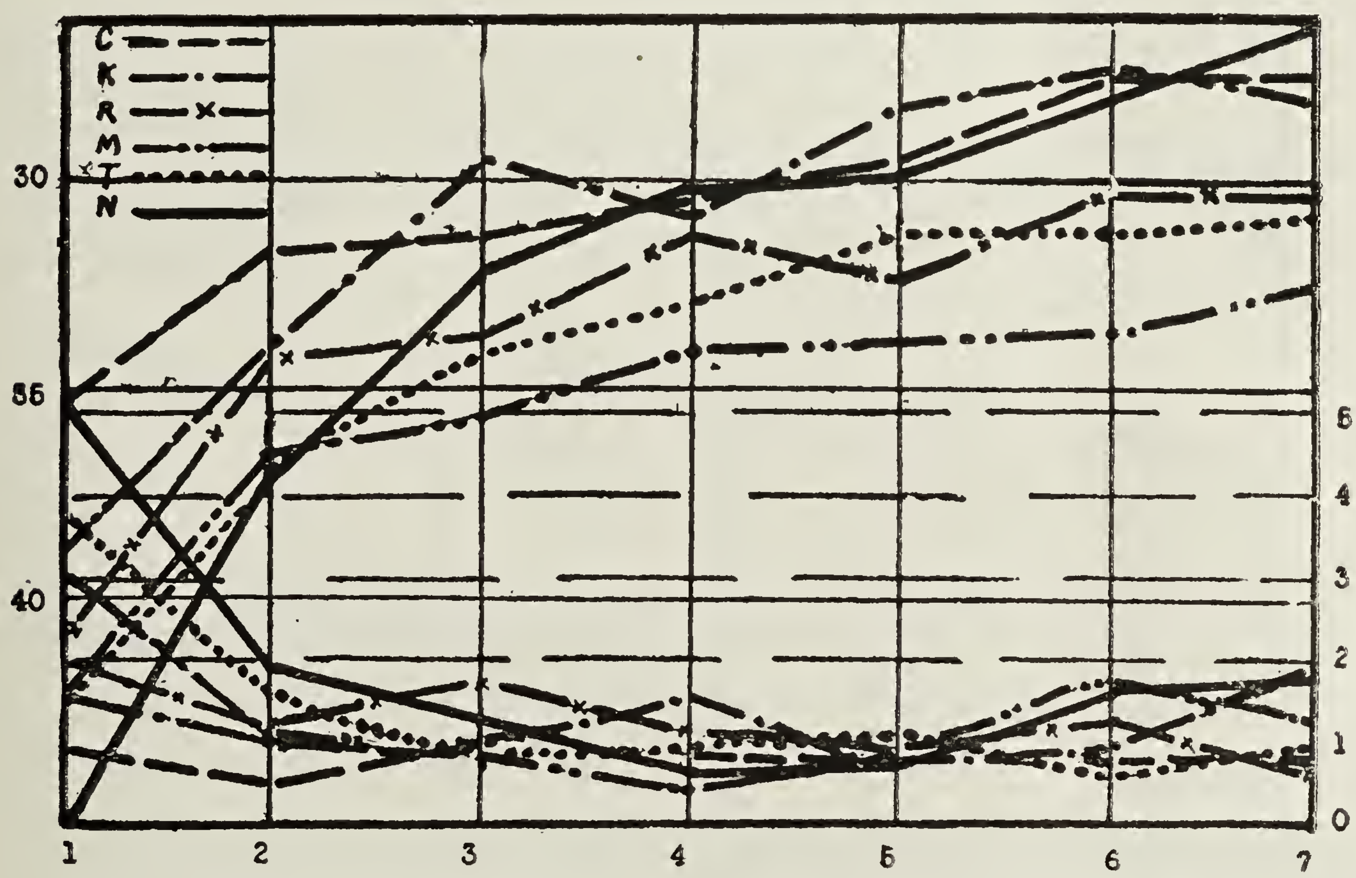


Fig. 6. Speed and variability in speed of six subjects on seven days. Figures at left, time in seconds; at right, mean variation in seconds; at bottom, days.

that: (1) the greatest diversity of performance appears on the first day; (2) progress is most noticeable during the first three days or thirty trials, after which it becomes very gradual; (3) with one exception subjects tend to maintain their relative positions on successive days.[2]

[2] Only one subject, N, shifts his position. This man evinced a remarkable

The mean of the first day's record is a more reliable index of the potential performance of an individual than is his "best time," since the most erratic subjects may show remarkable spurts of speed.

There is no relation discoverable between speed on the first day and the per cent of improvement in seven days.

On the first day, wide individual differences in variability appear; thereafter, all subjects seem to cling very closely to their mean performances, and those differences are not so evident.

The amount of improvement made on each day, and also the relative speed of the ten trials of each day, are indicated in Fig. 7. Increase in speed is very slight after the third day. Only

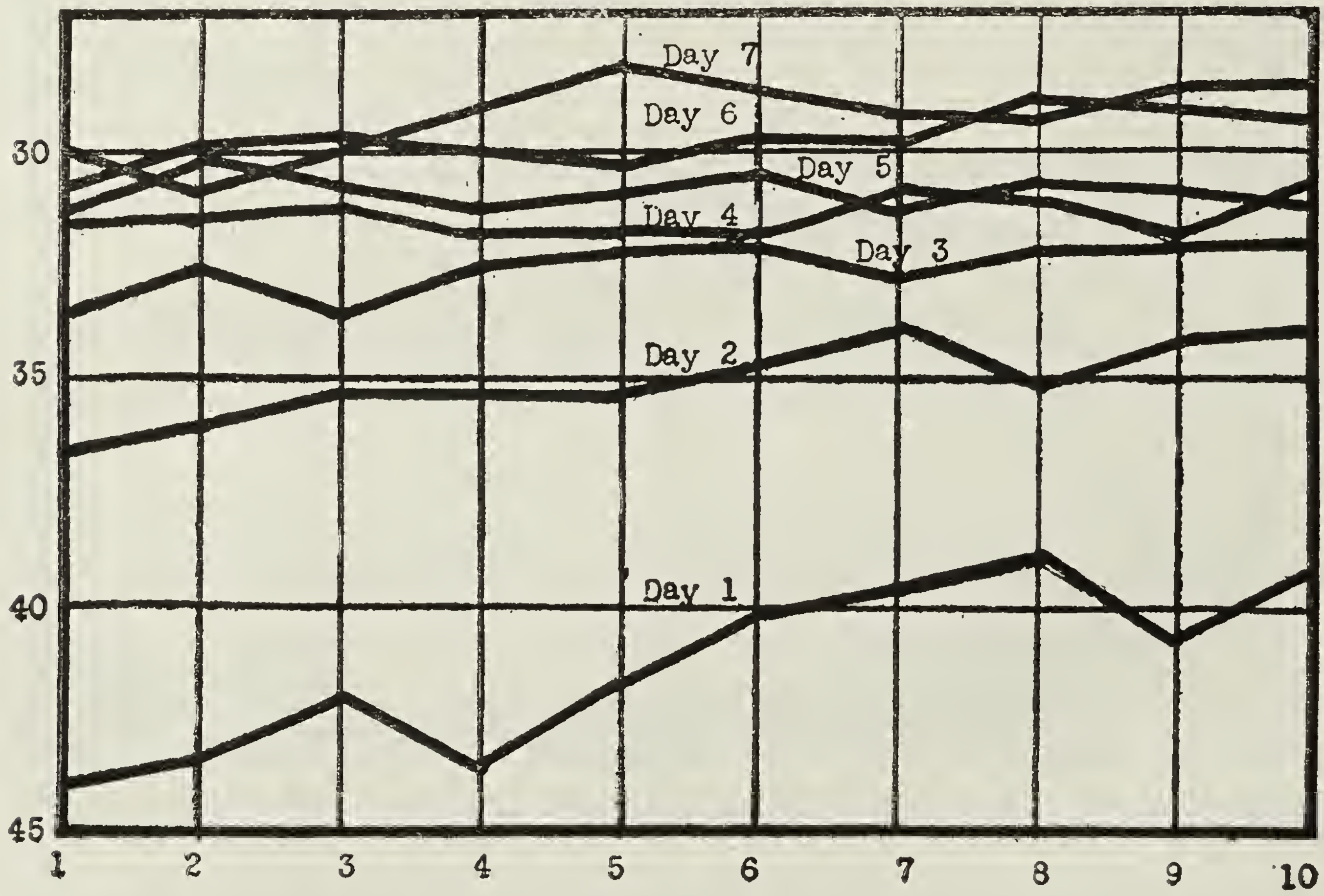


FIG. 7a. Mean time of all subjects in each of ten trials on all days.

ability for learning the order of the stimuli. By the second day, he had acquired the sequence of several "patches" of stimuli and would run these off, each immediately following its own stimulus, just as smoothly and regularly as a pianist playing a familiar musical number, but guiding himself by the notes. On each successive day, this subject extended the range of these memorized sections, and by virtue of this coup, rose from the rank of slowest to that of fastest. The other subjects did not carry the memorizing of sequence to so high a degree of success.

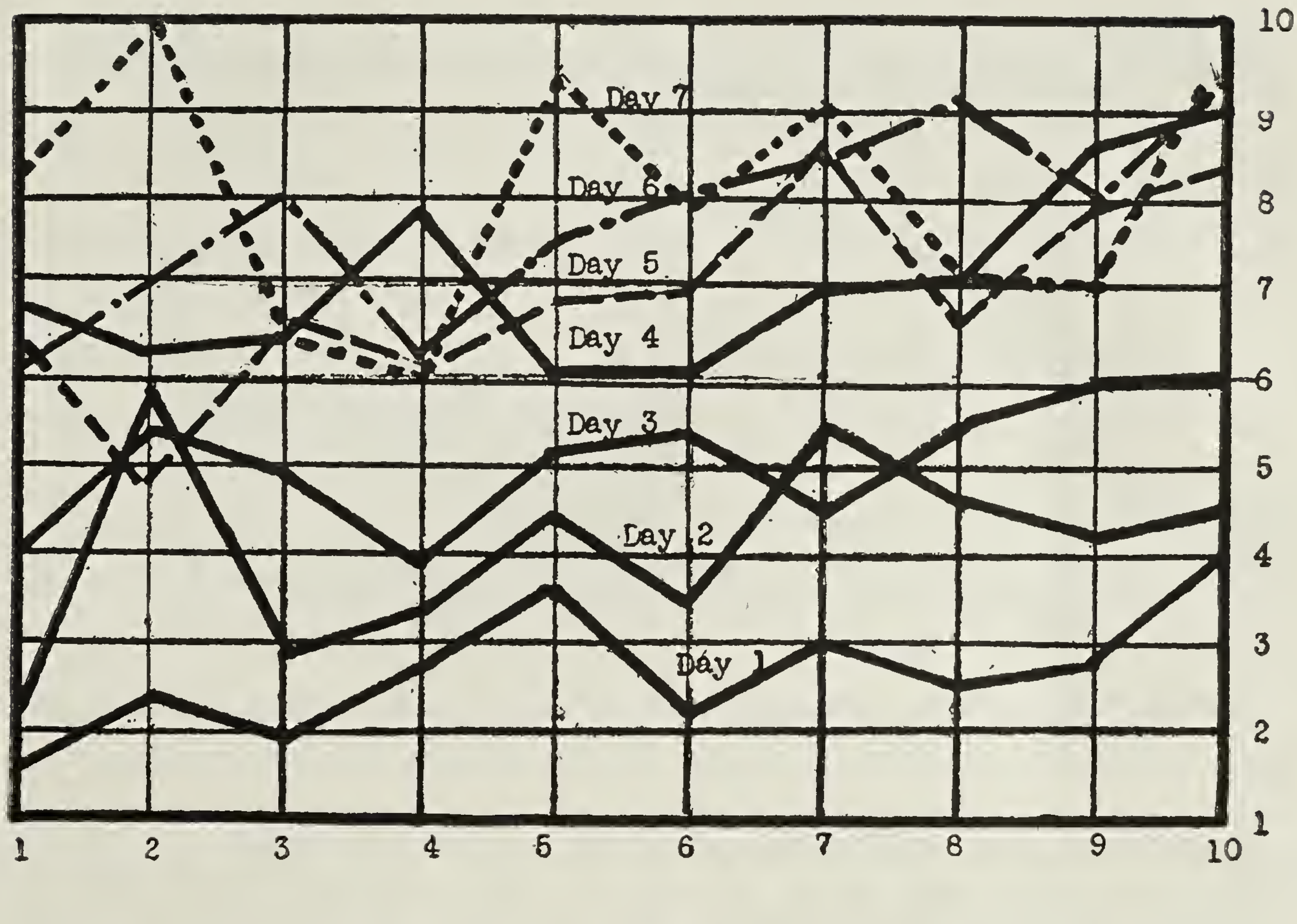


FIG. 7b. Mean number of errors for all subjects in each of ten trials on all days.

on the first and second days does any "warming up" seem to occur during the day's ten trials, and from the 7.6 seconds of total improvement on the first day to 2.5 seconds on the second day, a great diminution in gain is evident. No consistent crest of good performance, and no particular "breaking point" in the ten trials, can be found on any day.

As the subject becomes more familiar with the test, he loses caution and tends to keep up a fast, automatic gait, at the expense of accuracy. However, with one exception, each subject tends to maintain his relative accuracy in the performances of subsequent days. (See Fig. 8b).

While all the subjects become less accurate with increase of speed, it cannot be said that those who accelerate most in speed degenerate most in accuracy. Thus, the subject making the most gain in speed (N) declines the least in accuracy; while two other subjects (M and T) whose time records show high improvement, degenerate greatly in accuracy. Neither does the subject who

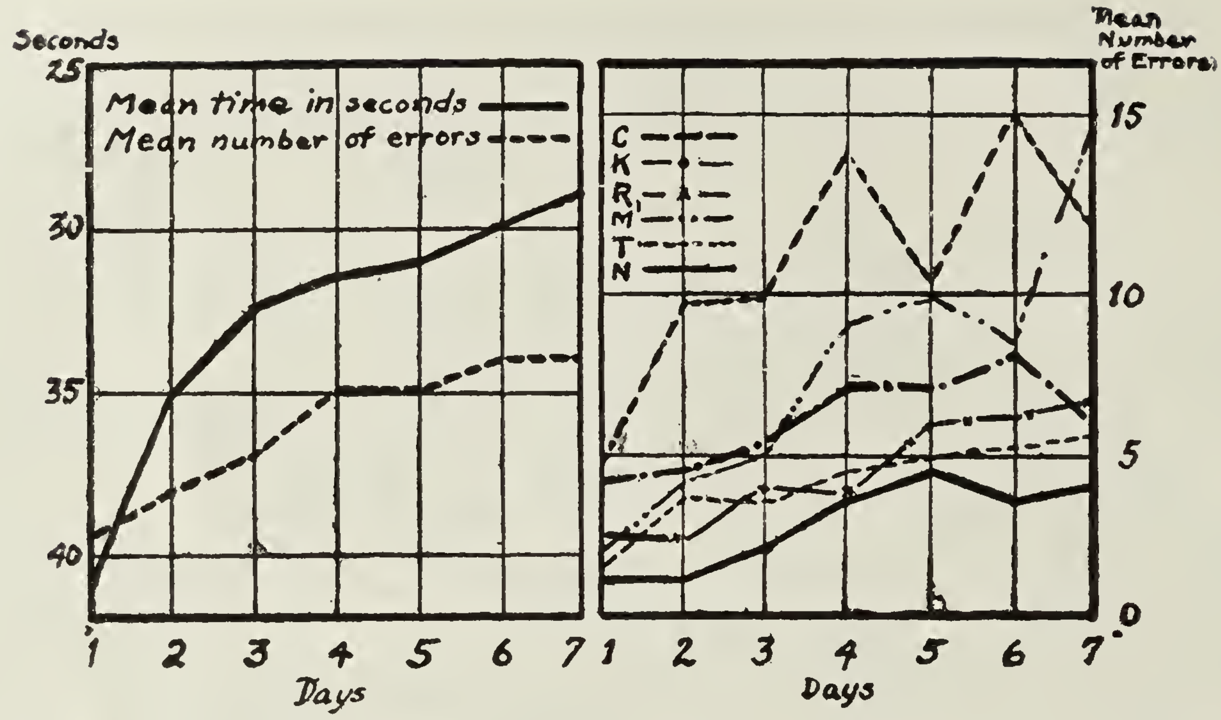


Fig. 8a. Speed and accuracy of six subjects combined, for seven days.
Fig. 8b. Number of errors of six subjects for seven days.

accelerates least (R) distinguish himself for accuracy. At any stage following the first day, just as on the first day itself, subjects are classified as fast and accurate, slow and accurate, fast and inaccurate, or slow and inaccurate. The individual tends to cling to his relative position, even during an extended period of practice.

"Hard" and "easy" places within the seventy-five reactions of each trial were very evident throughout the tests, both from the pauses and smooth flows in rhythm of reactions, and from the grouping of the errors in certain places within each row of the record. Investigation proved that these particular regions tended to appear uniformly among all the subjects, and tended to persist throughout practice.

The correlation between the distribution of errors on the first day, for all subjects, and on the second day, was r, .61, p.e. .05. The same distribution showed a correlation of r, .61, p.e. .05 with that of the seventh day; and of r, .68, p.e. .04 with that of the total of all days.

The distribution of errors in relation to the four respective fingers involved in committing them brings out the following results: (1) There is greater inaccuracy in the reactions of the two index fingers, with only one exception; (2) of the two index fingers, the one belonging to the right hand is generally the less accurate; (3) individual differences, while apparent in the errors committed by the index fingers, are much more pronounced with respect to the two extreme fingers. The relative accuracy of right hand and left hand fingers is subject to individual differences.

The general conclusions derived from these experiments are, that under the conditions obtaining,

(1) Whatever kind of stimulus be used, the speed of serial action increases with practice, rapidly during the first twenty-five or thirty trials, and then slowly for an indefinite period. Increase in speed is accompanied by a decrease in the variability of speed, as the subject strikes his "gait." Improvement during the day's trials, or "warming up," appears chiefly on the first day. When practice series with two kinds of stimuli are run in parallel, the characteristic rises, drops and plateaus in speed of one series are usually accompanied by similar changes in the other.

(2) Unless a rigid habit of accuracy is built up from the initial trial, accuracy degenerates as speed accelerates. But a habit of accuracy does not hamper the rise in speed, if developed consistently. Each day's performance is most accurate at first and least accurate at the end. Variability in errors does not generally decrease with practice. "Hard" and "easy" places, and tendencies of certain fingers to commit a disproportionate number of errors, persist through practice.

(3) Individual differences in speed and accuracy do not disappear with practice. The diversity of performance of subjects is greatest at first and tends to decrease. But subjects usually maintain their relative positions with respect to each other, in both speed and accuracy, throughout a practice period.

(4) Five trials are generally sufficient to indicate the relative capacity of subjects for speed and accuracy in this test; but the high practice curve renders ten trials more reliable.

Distributions of the Groups Tested, According to Speed and Accuracy

Together with a number of other tests, the serial action test was given to four classes of persons: (1) students, (2) army recruits, (3) musicians, and (4) stenographers.

Series I, Students.—The first group tested consisted of 152 university sophomores, 100 men and 52 women. In January, 1918, these were each given the series of motor tests described by Seashore (63, Chap. IX). For the serial action test, auditory stimuli, consisting of electric buzzers, were used.

The scores for speed in serial action (Fig. 9) showed a wide range—from 37 to 70 seconds, with the median at 56.4 seconds. Women did not, as a group, quite equal the men in speed, and they also tended to make more errors (Fig. 10).

Series II, Army Recruits.—The visual form of serial action (E symbols) test was one of several tests given to miscellaneous recruits applying for admission to the army school in radio-

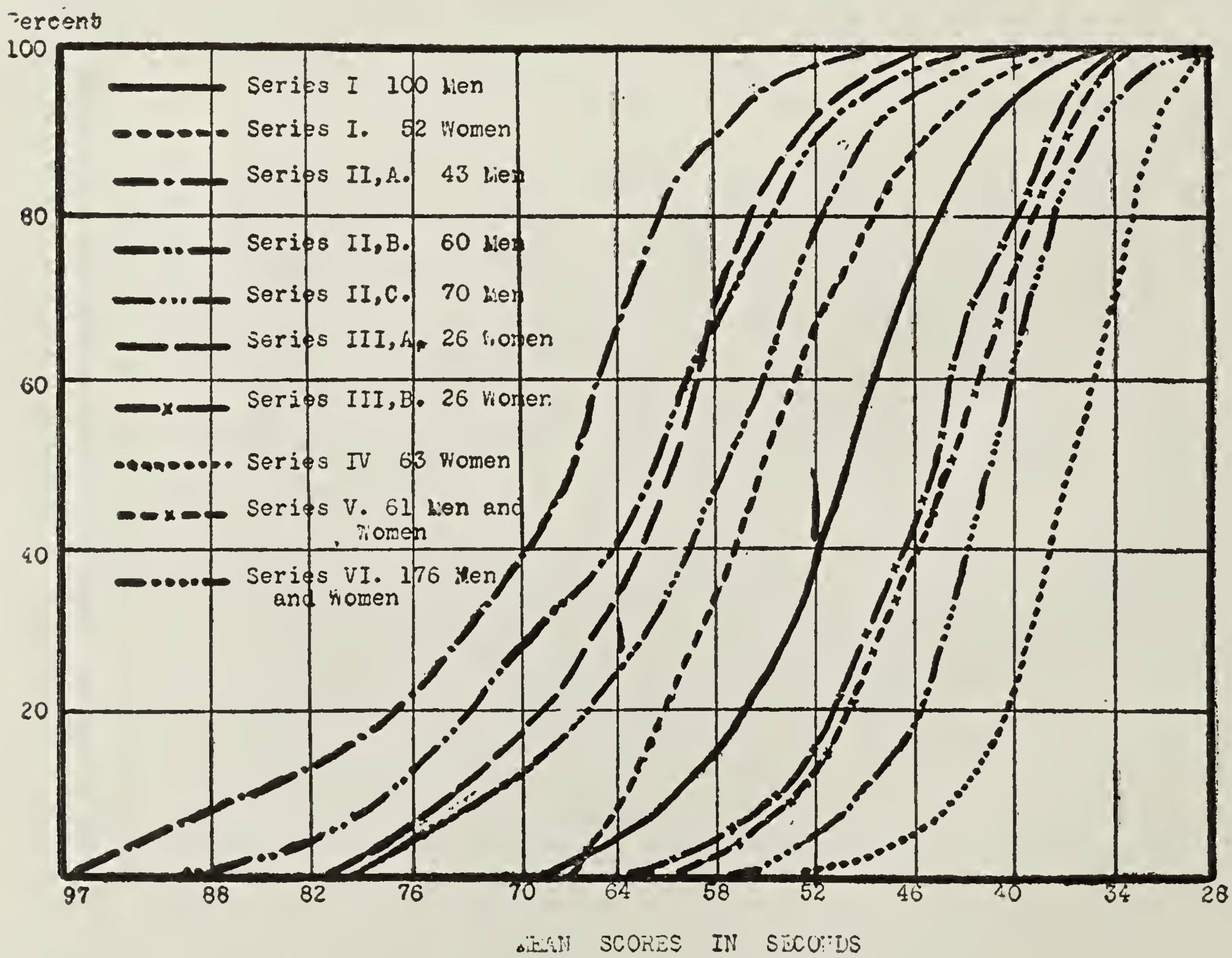


Fig. 9. Distribution of speed scores by groups.

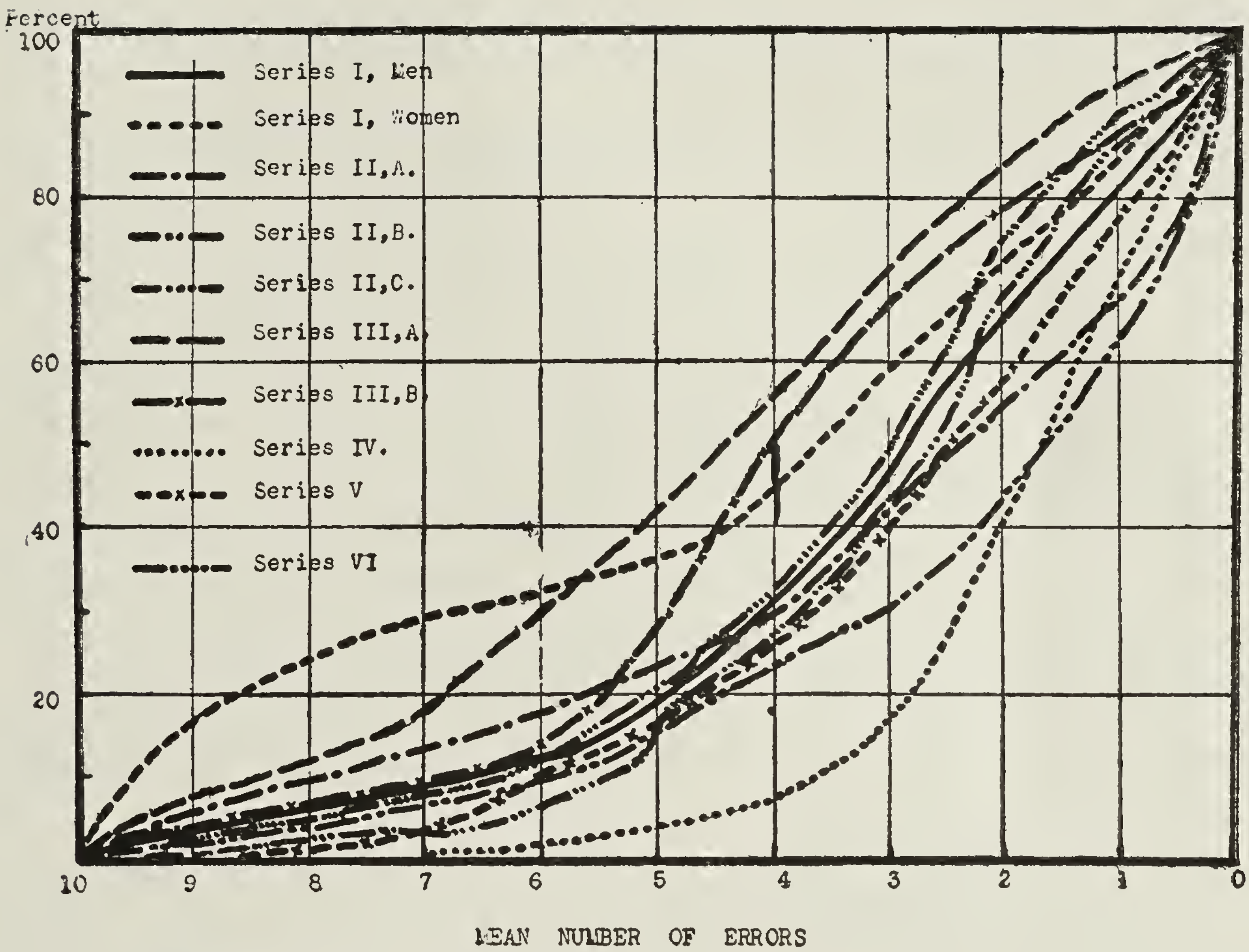


FIG. 10. Distribution of errors by groups.

telegraphy at the University of Iowa during the summer of 1918.

A. Forty-three recruits arrived and were tested early in June, 1918; nine were rejected on the basis of poor performance in this and other tests. This group showed wide diversity in ability, the scores in serial action ranging from 52 seconds to over 100 seconds, with the median at 73 seconds. The distribution is the most irregular of any group. Errors also showed great irregularity.

B. In August, sixty men appeared for the tests, thirty-two of whom were admitted to the course. The median speed in visual serial action was 63.9 seconds, almost 10 seconds faster than the previous group. The range was relatively small, and in accuracy a good record was attained.

C. Seventy recruits were tested for admission to the training course in October. Auditory serial action, with telephones, was used. The range in serial action scores is more narrow than in previous groups, and the median (60.9) shows greater speed. However, the number of errors is greater than in the preceding group. Selection in this group was prevented by the influenza epidemic.

Series III, Musicians.—The serial action test in both auditory (with telephones) and visual forms was one of the measures used by Dr. E. A. Gaw in making a survey of musical talent in the Northwestern University School of Music, during December, 1918. Twenty-six women, all musicians of considerable training, composed this group. For visual serial action, a simple letter arrangement, similar to that described by Coover and Angell (20) was used. Each subject received, first, five trials with visual and then five trials with auditory stimuli. The speed in the visual series (median, 51.5 seconds) was fast, but in the auditory series was slow (median, 64.8). The range was wide, and in the number of errors committed these subjects exceeded any others tested.

Series IV, Music Students.—Sixty-three students in the University of Iowa School of Music, all women, were given the serial action test, in 1920, with electric lights as the stimuli. The scores show very short reaction-times, a narrow range, and few errors.

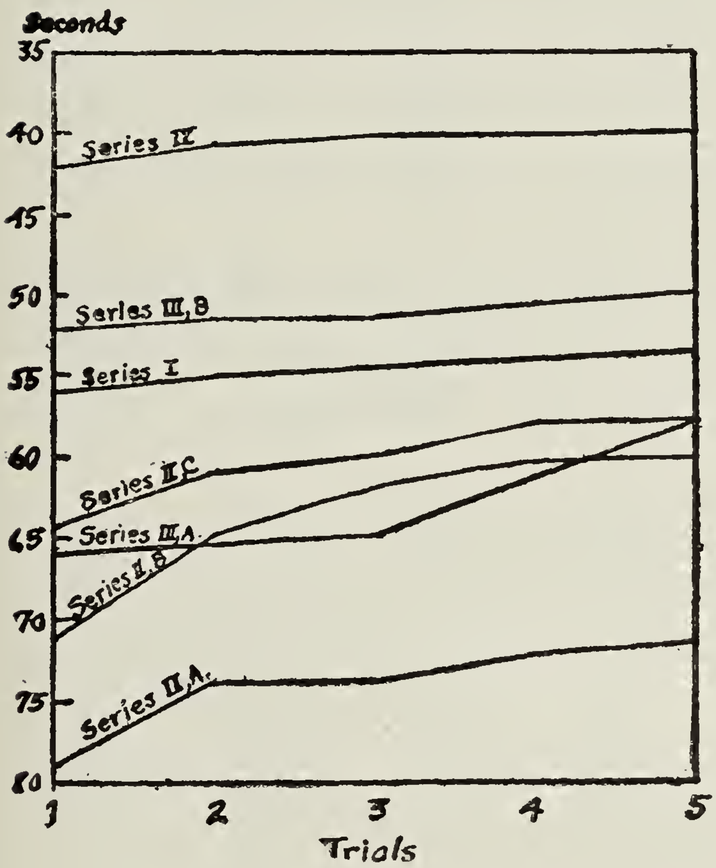
Series V, Stenographers.—Sixty-one students in the typewriting courses of the Cedar Falls (Iowa) High School and of the Iowa Teachers College were given the same test by Mr. Ben W. Robinson in 1920. The subjects were mostly women, varying considerably in age and education. The resulting scores ranked this group next to those in Series IV in speed, while the number of errors was greater.

Series VI, Stenographers.—One hundred seventy-six students taking courses in typewriting at the three Des Moines high schools were also tested by Mr. Robinson. Only nine of the subjects were men. This group stands between those of Series IV and V, in speed, and in accuracy falls below them both.

General Comparisons.—(1) No consistent sex differences are shown, in either speed or accuracy.

(2) As is shown in Fig. 11, giving the median time for each of five trials, electric lights produce the quickest reactions, digits

are second (for educated subjects), tones are third and visual symbols (E) are fourth. The nature of the stimulus does not seem decidedly to affect accuracy, but there is slightly greater accuracy in the visual tests (Fig. 12).



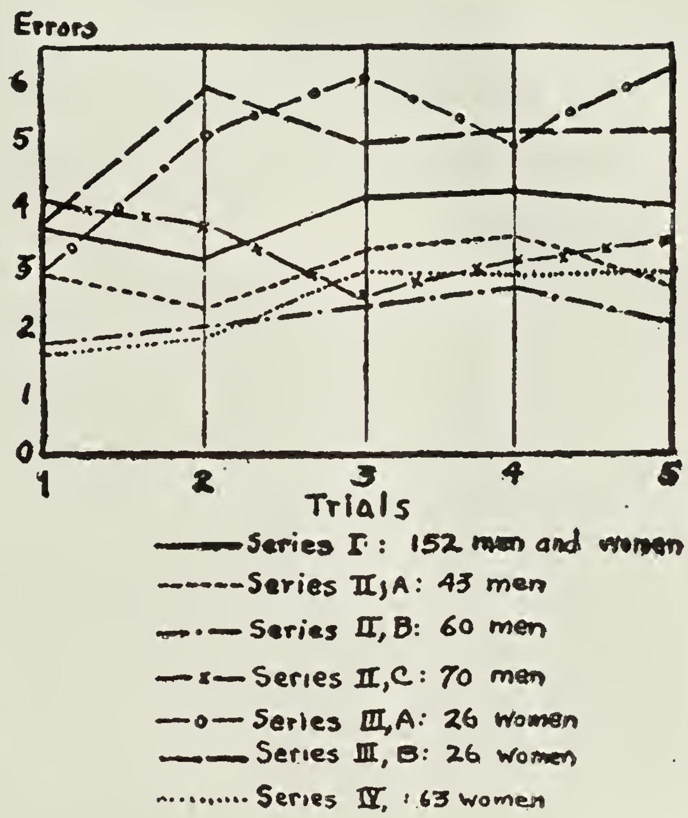


FIG. 11. Median scores in each of five trials of various groups.
FIG. 12. Median number of errors in each of five trials of various groups.

(3) The medians show improvement in speed with each successive trial. The amount of this improvement is most marked under those conditions which cause slow reactions. The number of errors tends to increase during the test, but not consistently.

The Distribution of Errors in Relation to the Sequence of Stimuli

The order or sequence in which the stimuli come has considerable significance in the location of errors. Certain regions in the succession of stimuli are "easy," calling out smooth responses, while other places are "hard," causing errors, pauses and confusion.

The number of errors is found to depend upon the probability of the appearance of each stimulus; that is, the subject is always expecting the stimulus which has been absent the longest, and expecting least the one which was most recent. The results are as follows: The stimulus which has been absent the longest has only 36 per cent of the errors, although its proportional share would be 57.5 per cent. The stimulus which has been absent next to the longest, has 30 per cent of the errors, while its share would be 25.2 per cent. The most recent stimulus has 34 per cent of the errors, while its proportional share would be only 17.3 per cent. Thus the least expected stimulus causes three times as many errors, proportionally, as the most expected stimulus.

Other causes of errors in certain regions are the maintaining of symmetrical reactions after the stimuli have ceased to come according to symmetrical order, and the "spreading" of mistakes over successive reactions.

Figure 13 represents the distribution of 2547 errors in 420 trials with electric lights as stimuli, and of 2257 errors in 426 trials with tones from telephones as stimuli, the order of sequence being identical in the two series. The subjects were different. The "hard" places in the visual tests are also "hard" in the auditory. In fact, the correlation between the two arrays of errors is r, .62, p.e., .05.

This comparison of visual and auditory stimuli shows that, while the index fingers in both cases cause disproportionally many errors, this relation is much more pronounced in the visual tests. In the latter, the index fingers make two-thirds of the mistakes. Therefore, the inaccuracy of the index finger is due largely to the fact that discrimination of position is not so easy in the middle pair as in the extremes. That is, a radical shift of position by the visual stimulus is more readily discriminated than is a less extensive shift of the visual stimulus. In the auditory tests, wide separation of all four stimuli caused the moderate shifts to be more readily discriminated than in the visual tests.

The Relation of Serial Action to Other Measures Used

The relation of speed to accuracy and variability.—The results of correlating[3] the mean time and mean error records of the

[3] Throughout this study, in figuring correlation coefficients, the Pearson products-moments formula has been followed, except when the number of

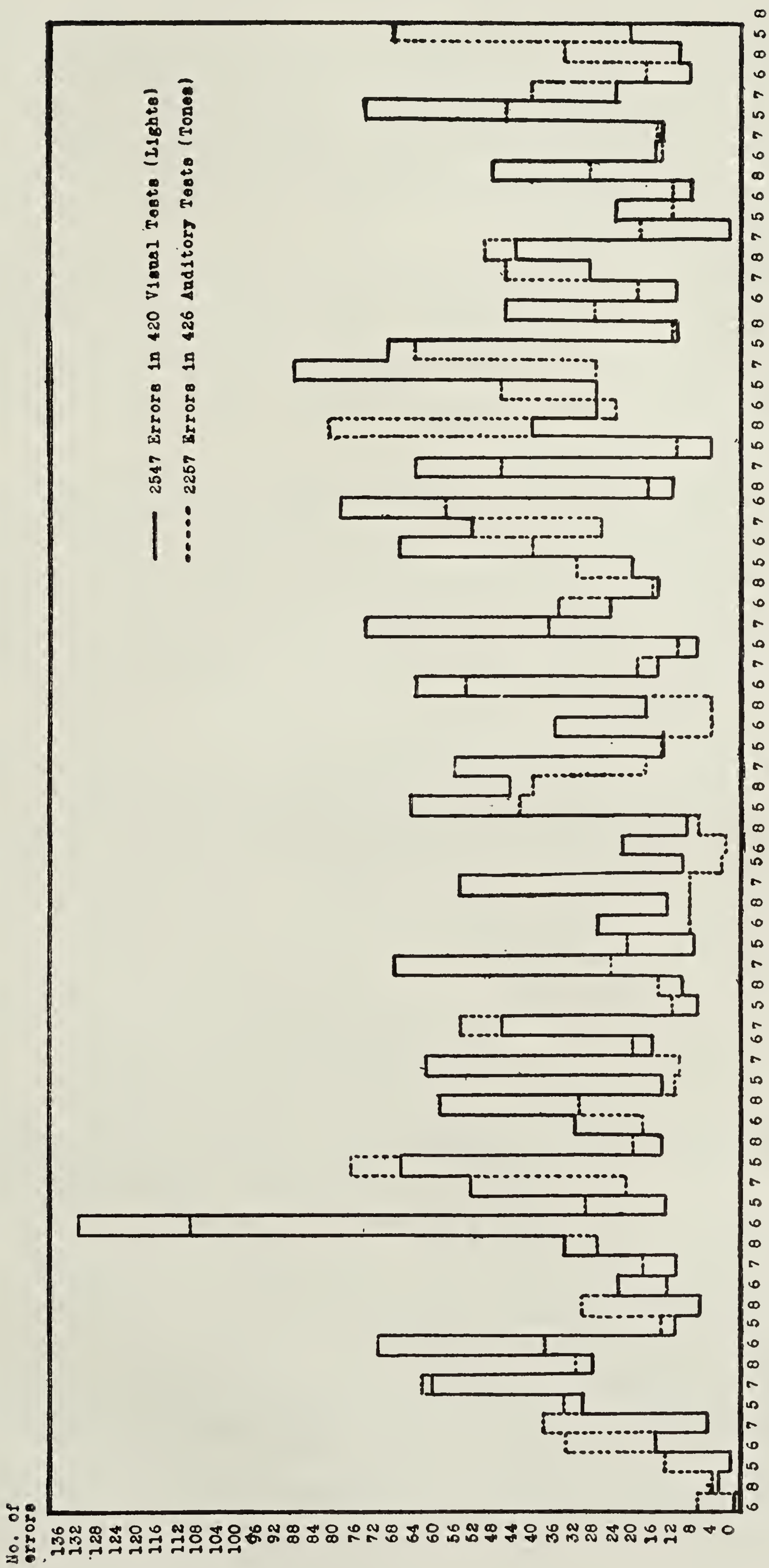


FIG. 13. Distribution of errors according to sequence of seventy-five successive stimuli.

subjects, are shown in Table 1. There is no consistent relationship between mean speed and mean accuracy; the three largest groups of subjects fail to show definite correlation. But positive correlations appear in some of the smaller groups and these are the groups in which the most caution was observed in keeping errors at a minimum.

All subjects could be classified on the basis of their performance, into four kinds, or types: (1) quick-accurate, (2) quick-inaccurate, (3) slow-accurate, and (4) slow inaccurate. There were, however, some marginal cases which did not belong definitely in any one class.

The relation between a subject's speed, from his first to his last trial, and his accuracy, is not consistent. Usually, his first trial is the slowest and most accurate, but speed does not develop at a consistent expense in accuracy. As a result, no constant could be secured which would enable the experimenter to reduce errors to a time basis.

Several methods of evaluating errors so as to secure a single score, in terms of time, were tried out. One of these gave additional credit to the time scores of subjects who were more accurate than the median, and deducted a percentage from those who were less accurate than the median. This method was too complex for general use.

Another weighting plan for errors was based on this formula:

$$\text{Score} = \frac{\text{Total time for all trials}}{\text{Total no. of reactions minus no. of errors}}$$

The scoring method suggested by Link (47) was also tried out. However, since the subject who made more errors did not thereby secure any clear advantages in speed, over his more accurate companions, and since the errors were generally kept down to a fairly uniform level, speed alone was adopted for use as the serial action index.

Speed and mean variation in speed showed a considerable negative correlation (*e.g.*, r, .62, p.e., .05 in the 70 cases of Series

cases was less than 30. There the Spearman "foot-rule" was used and designated as R.

II, C). This meant simply that the subjects who worked the fastest also showed the least variability.

TABLE I. *Correlation of mean speed and mean accuracy* (Speed from fast to slow, and errors inversely ranked)

Series I	151 cases	r,	.00		
Series II, A	43 "	r,	.48,	p.e.,	.08
Series II, B	60 "	r,	.36,	p.e.,	.07
Series II, C	70 "	r,	.20,	p.e.,	.08
Series III, A	26 "	r,	.31,	p.e.,	.11
Series III, B	26 "	r,	.12,	p.e.,	.12
Series IV	63 "	r,	.32,	p.e.,	.07
Series V	61 "	r,	.13,	p.e.,	.08
Series VI	174 "	r,	.13,	p.e.,	.05

The Relation of Serial Action to Other Motor Tests

As is evident from Table II, a low positive correlation obtains between speed in serial action and the time of simple reaction to sound; and a similar relation appears with reaction after discrimination and choice.

TABLE II. *Correlation (r) with simple reaction to sound*

Series I	151 cases	r,	.29,	p.e.,	.05
Series III, B	25 "	r,	.46,	p.e.,	.09

Correlation (r) with complex reactions (to sound)

Series I	150 cases	r,	.35,	p.e.,	.05
Series III, A	26 "	r,	.37,	p.e.,	.10
Series III, B	26 "	r,	.37,	p.e.,	.10

The correlation of speed in serial action and precision of movement, as measured by the target test, is negligible. This fact appears in the tests of both Series I and II, A, and B. Furthermore, no correlation exists between accuracy in serial action and accuracy in the precision test. The performance of a wrong reaction in serial action is quite unlike inability to make a fine, steady adjustment in repeated movements.

Strength of movement, as indicated by the best of three trials with the Smedley dynamometer, was also compared with serial action records in the group of 150 students. The coefficient was r, .28, p.e., .05, indicating a possible low positive correlation.

Motility, measured by the maximum rate of tapping, shows a low positive correlation with speed in serial action, as is evident in Table III.

TABLE III. *Correlation (r) with Motility Test*

Series I	151 cases	r, .25,	p.e., .05
Series II, A	43 "	r, .24,	p.e., .10
Series V	61 "	r, .27,	p.e., .07
Series VI	174 "	r, .23,	p.e., .05

That these various low correlations point to a tendency of serial action to agree with the other motor tests in the classifying of subjects, is illustrated by a comparison of grades based on quintile standing. The forty-three recruits in Series II, A, were thus graded from very superior to very inferior (A, B, C, D, and E) in the motility and serial action tests. Of these subjects:

13 maintain the same rank in both tests,
20 differ one grade in rank.
8 differ two grades in rank, and
2 differ three grades in rank.

Similarly in tapping for accuracy (a test in which the examiner called out rapidly in succession the number of times which the subject was to tap),

16 have the same rank as in serial action,
17 differ one grade in rank,
8 differ two grades in rank, and
2 differ three grades in rank.

A similarly rough corespondence occurs with the other tests showing low correlations with speed in serial action.

The relation of serial action to code tests.—A low positive correlation between speed in serial action and scores in the two code tests was generally found. These code tests, the "Civil War" code as described by Terman, and the "Russian" tapping code (in which the subject is given a scheme for transliterating the alphabet into a code of taps, and then must interpret the words which are tapped by the experimenter) were given to the three groups of army recruits.

TABLE IV. *Correlation (r) with the Civil War code*

Series II, A	43 cases	r, .43,	p.e., .09
Series II, B	32 "	r, .34,	p.e., .11
Series II, C	67 "	r, .20,	p.e., .08

TABLE V. *Correlation (r) with the Russian tapping code*

Series II, A	43 cases	r, .30,	p.e., .10
Series II, C	69 "	r, .44,	p.e., .07

These low correlations indicate a rough tendency on the part of the tests to agree in their ratings of subjects. In terms of grades, the relationship is shown in the following comparison of scores made by forty-three recruits in the "Civil War" code and serial action:

17 maintain the same rank in the two tests,
15 differ one grade in rank,
8 differ two grades in rank,
3 differ three grades in rank.

The relation of serial action to the Vasey vocabulary test.—No consistent relationship between serial action and the Vasey vocabulary test was found. The largest group of subjects showed no definite correspondence, while the two smaller groups indicate a low correlation.

TABLE VI. *Correlation (r) with Vasey vocabulary test*

Series II, C	70 cases	r,	.31,	p.e.,	.07
Series V	61 "	r,	.35,	p.e.,	.07
Series VI	174 "	r,	.14,	p.e.	.05

The relation of serial action to army Alpha intelligence test.—Here, again, the largest and most representative group does not show any definite relation between the tests compared. The smallest group, however, gives a fair correlation. The evidence is therefore inconclusive, although—considering the code and the vocabulary tests, as well as the Alpha test—the data point to a slight dependence of score in serial action upon intelligence.

TABLE VII. *Correlation (r) with Alpha intelligence test*

Series IV	41 cases	r,	.51,	p.e.,	.08
Series V	61 "	r,	.20,	p.e.,	.08
Series VI	174 "	r,	.14,	p.e.,	.05

The serial action test generally stands in a middle position among the different tests used; that is, it agrees roughly with them in its classifications. Thus the nine recruits of the June group who were rejected on account of low standing in the test (each given equal weight), ranked as follows in serial action: 1, B; 2, C; 3, D; and 3, E. In the August group, a score of 67 in serial action roughly divides the successful from the unsuccessful applicants.

The serial action test picked out, with considerable certainty, nervous, high-strung subjects. This type appears at the extremely slow or inaccurate ends of the distribution curves.

Application to Vocational Guidance and Selection

In this investigation, serial action was studied in its relationship with three psycho-motor activities which have vocational significance: musical action, telegraphy and typewriting. Great difficulty was experienced, however, in securing satisfactory criteria of ability or of success in these activities.

Musical action.—Such difficulties as the following must be considered in judging the test by means of criteria in music. Professors' ratings of their pupils are subject to those very individual biases and fallacies which it is the purpose of objective tests to eliminate. Each instructor has only a small number of students to rate, and there is no way of equating the instructors' grades so that they will be mutually comparable.

Again, some students enter the conservatory already drilled and polished by musical training, while others are almost unskilled novices. Some spend the entire day upon musical efforts, and others only occasional hours.

The relative performance in serial action, of persons trained

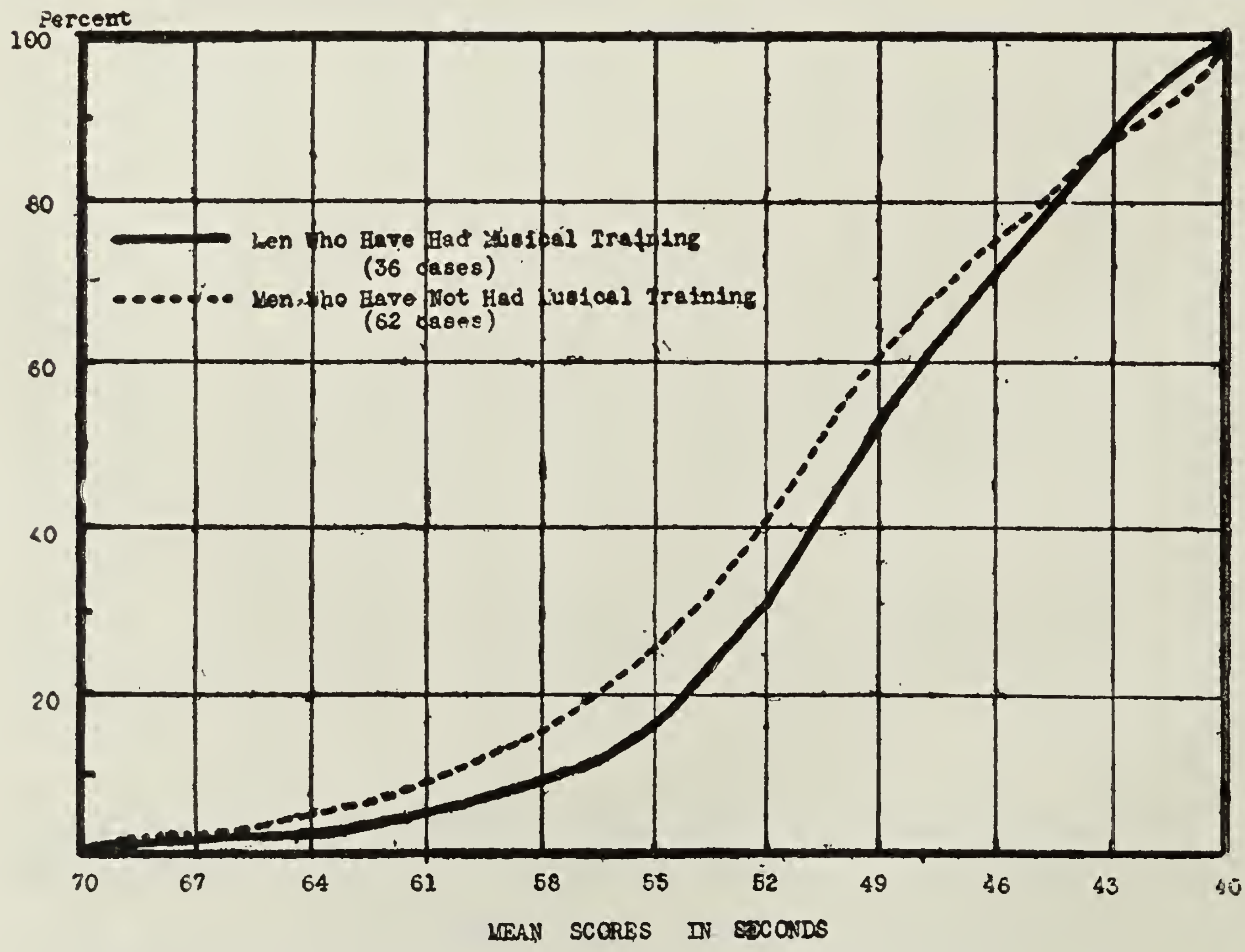


FIG. 14. Scores in serial action of men who have had musical training and men who have not.

and untrained in musical performance was studied. Figure 14 shows the percentage distributions, in speed of 36 university men who have had musical training and of 62 men who have had none. The two groups are almost identical in test scores. This fact does not argue against the value of the test for rating musical talent, since "surveys of public schools show clearly that very little correlation exists between the possession of musical talent and the selection of children for musical education" (63, p. 4). The data here indicate that training in musical performance does not, as such, confer any advantage upon any subjects taking the test. Native motor capacities, more than acquired refinements of action, determine performance in the test.

Correlations were first sought with standard tests of musical talent. The visual serial action test was found to correlate somewhat with the test of rhythmic action, the coefficients for the Northwestern and the Iowa University groups being r, .41, p.e., .12 and r, .50, p.e., .08, respectively.

The test was then studied in relation to the ratings which, entirely independently of the motor tests, were given to their students by the instructors in music at Northwestern University, under the following heads: Application, Achievement, Ambition, Reading Ability, Memorizing Ability, Ear Training in Class, and Sight-Singing in Class. Since it was evident that an estimate of all-around attainment, rather than of specific elements in attainment, lay at the bottom of these various ratings, the sum of each individual's ratings was accepted as the best available criterion of musical performance. Similarly, the grades of the music subjects at Iowa University, given by the instructors, under the heads of Sight-Singing, Control of Rhythm, Application and Progress, were added together to furnish a criterion. The Northwestern University ratings furnished correlations of r, .52, p.e., .11 with visual serial action, and r, .35, p.e., .13 with auditory serial action. In the Iowa University group, the correlation was r, .26, p.e., .10. A more reliable comparison might be made by classifying the students simply as either "above average" or "below average" in general attainment. In Table I is found the result of comparison on this basis.

TABLE I. *Comparison of performance*

		Serial action Below average			Above average		
Musical Achievement	Above average	Series	III, A	4	Series	III, A	8
		"	III, B	5	"	III, B	8
		"	IV, ...	7	"	IV, ...	12
	Below average	Series	III, A	9	Series	III, A	4
		"	III, B	8	"	III, B	4
		"	IV, ...	12	"	IV, ...	7

It is evident that, in each series of tests, there is a rough tendency for those who are above average in serial action to be above average in musical achievement ($\frac{8}{12}$, $\frac{8}{12}$, $\frac{12}{19}$), while those who are below average in the test tend to be below average in musical achievement ($\frac{9}{13}$, $\frac{8}{13}$, $\frac{12}{19}$).

That visual serial action indicates roughly the subject's ability for sight-reading is shown by the *mean* ranks in the test, of the Northwestern students, graded by letter according to success in sight-reading: A, 9; B, 10; C, 14; D, 25. The "A" and "B" students were least clearly differentiated. In the Iowa ratings, the correlation between performance in the test and success in sight-reading was r, .43, p.e., .09. In that group, those who were above average in serial action were generally above average in sight-reading, while those who were below average in serial action tended to be below in sight reading.

There was some correlation of serial action with professor's rating in "control or rhythm" (.37, p.e., .09). No definite correlation with such single ratings as those on Application, Ambition or Progress, has been established for either group.

While these data do not furnish conclusive proof, they give encouraging evidence that serial action measures abilities which partially determine success in musical action.

Radio-telegraphy.—The three groups of army recruits applying for training in radio-telegraphy were of a most miscellaneous character. Not only did they vary enormously in education and experience, but also in previous training in telegraphy. Each group included expert professional telegraphers, somewhat experienced apprentices and amateurs, and "green," unskilled men-of-all-work. The relation of the serial action test, therefore, to achievement in telegraphy was greatly complicated.

The distribution of these applicants according to grades in serial action showed (as Table II illustrates) that the operators and apprentices of previous training included more than a proportional share of the superior subjects in serial action. This slight superiority of telegraphers is perhaps due, not to their training as such, but to the selective process lying behind it, by which capable men generally acquire some profession or field of interest, while less capable men remain unskilled.

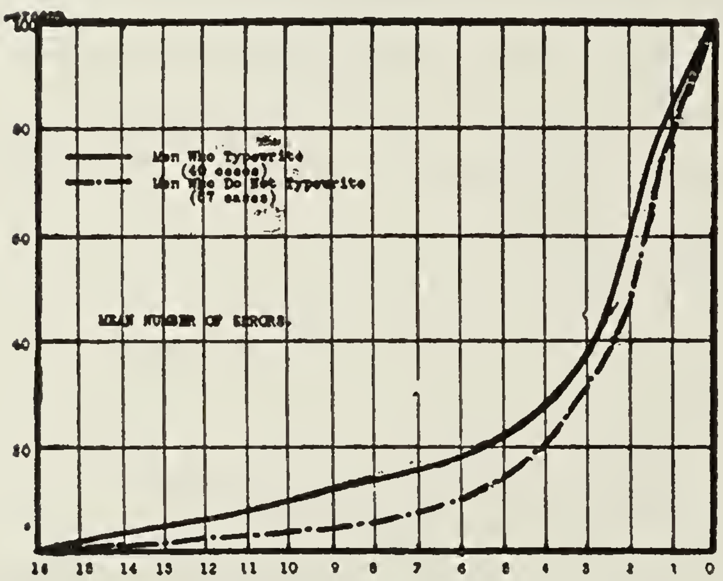
TABLE II. *Distribution of 43 recruits by grades in serial action*

	A	B	C	D	E
Operators	2	1	5	1	0
Apprentices	1	4	2	1	0
Unskilled men	1	4	11	7	3

The eight weeks' course of training in radio-telegraphy which each group received, was interrupted by "fatigue" duties, military drill, transfers, and other distractions. The training of the last group was seriously disrupted by the influenza epidemic. At various times during the training, particularly of the first two groups, tests of speed and accuracy in sending and receiving words by telegraph were given to the subjects. In the second group, these tests came periodically, once a week.

Achievement in telegraphy, as thus measured, was taken as the criterion with which the serial action test was compared. No correlation between scores in serial action and ability in sending or receiving words telegraphically were apparent for the groups as a whole. Neither did accuracy in serial action evince any such relationship. Various other means of comparing the respective performances failed to demonstrate any relationship. If the comparison of achievement were limited to those men who completed the course and had entered it entirely ignorant of telegraphy—and such a comparison would alone be entirely just to the test—the number of cases would be so reduced that the results, although favorable, would be unreliable for any general conclusions.

Typewriting.—In Fig. 15 are given the percentage distributions, in serial action speed, of two groups of university men: one group of 40 men who could typewrite, and the other, of 57 who could not. Fig. 16 shows the relative accuracy of the same two groups. A slight advantage in speed, but no advantage in accuracy, is apparent on the side of those subjects who could



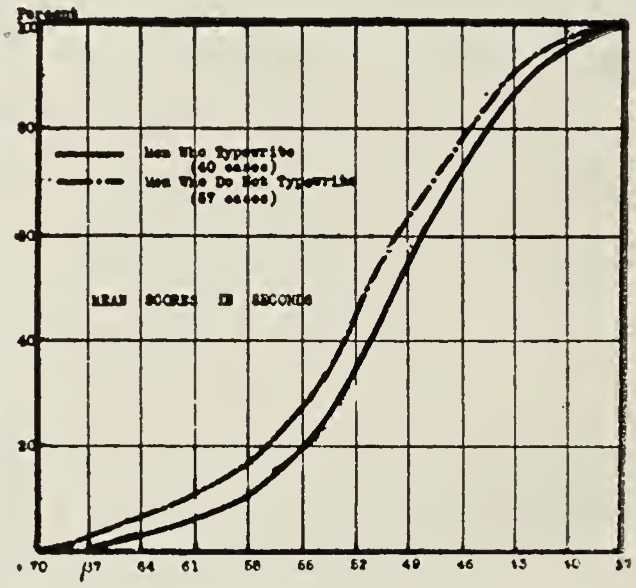


FIG. 15. Scores in serial action of men who typewrite and men who do not.
FIG. 16. Accuracy in serial action of men who typewrite and men who do not.

typewrite. This slight superiority may be attributed to the greater economy and ease of key-manipulation which comes with practice in typewriting. The distribution curves of speed, for Series V and VI, in which the subjects were students of typewriting, did not show quite as quick reactions as the distribution of musical students (Series IV). Practice in typewriting is not as significant a factor in this test as certain other variables such as maturity and native capacities.

The relation of scores in serial action to attainment in typewriting was especially investigated in the group of 176 students in typewriting at Des Moines. The criteria of ability to typewrite consisted of (1) instructors' ratings and (2) a "speed test" in typing.

When the gross scores of the 176 subjects in the speed-of-typewriting test were correlated with speed scores in serial action, the coefficient was found to be r, .15, p.e., .05. The correlation of accuracy in the typing test with accuracy in serial action was r, .10, p.e., .05. Both of the criteria were regarded, by instructors as well as experimenters, as quite unsatisfactory.

Conclusions

The conclusions to which this investigation has led may be summarized as follows:

(1). A "personal equation" of speed in serial action has been found. There are relatively fixed types of subjects apparent in this measurement of motor capacity. Four kinds of reagents appear: quick-accurate, quick-inaccurate, slow-accurate and slow-inaccurate.

(2). No consistent relationship obtains between mean speed and mean accuracy of serial action. Relative position in speed does not generally indicate relative position in accuracy. Similarly, in the trials of each subject, a relatively fast or slow time in any trial does not consistently entail a proportionally large or a proportionally small number of errors.

(3). (a) Performance in serial action shows some correlation with attainment in other motor tests, viz., simple and complex reaction, strength, motility, and rhythmic action. The correlations are generally low but indicate a rough agreement in the classification of subjects.

(b) The test furthermore rates subjects in general agreement with scores in the "Civil War" code test and the "Russian" tapping code test.

(c) Capacity in serial action shows only a slight relationship to ability as measured by the Vasey vocabulary test and army alpha. The serial action test cannot be regarded as an "intelligence" test analogous to these tests; it measures the subject's motor capacities while the "intelligence" test involves more definitely the conceptual and higher associational process.

(4). From the comparisons of serial action scores with criteria of proficiency in musical action, evidence was found that the serial action test indicates relative capacity for musical action, especially for sight-reading. The criteria for competence in telegraphy were so rough, and the candidates were so miscellaneously composed of experienced telegraphers and unskilled beginners, that no satisfactory comparisons with serial action scores were attained in that field. Correlations of test scores with students' proficiency in typewriting were low or negligible; but, because the factors for correlation were possibly not well chosen, the data were regarded as inconclusive.

(5). Among the factors which have affected the results of comparisons with practical criteria, the following are especially important: (1) The nature of the subject's task in the test differs from that of his vocational activities in the strain or pressure under which he takes the test. An equalization of incentive and of demand is needed. (2) The widely different training and experience of subjects, both in their vocational and avocational aspects, require consideration and sometimes the use of partial correlation. (3) The forcefulness and suggestion of the individual giving the test plays a very significant part in the subject's performance, even when the verbal instructions are strictly standardized. (4). The criteria used to gauge vocational success must be made more satisfactory. When such factors as these are definitely controlled, some measure of serial action will probably prove its usefulness.

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